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THE ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND ASTRONOMICAL PHYSICS

Founded in 1895 by GEORGE E. HALE *and* JAMES E. KEELER

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THE ASTROPHYSICAL JOURNAL

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ON THE APSIDAL MOTION IN α VIRGINIS

By W. J. LUYTEN and E. EBBIGHAUSEN

ABSTRACT

The new orbit of the spectroscopic binary α Virginis derived by Struve and Ebbighausen has been compared with that of Baker, and a period for the apsidal revolution of 114 years (about ten thousand times the period of orbital revolution) derived. Calculating the probable dimensions of the stars, and using Struve's observations on the velocities of axial rotation, the conclusion is reached that the stars have broken away from tidal control and that the brighter component, at least, rotates considerably faster than it revolves. Rough estimates for the density concentration are deduced by applying Russell's and Walter's formulae.

The possibility of obtaining direct evidence of the internal density concentration in stars by making use of observed apsidal rotation in close binaries was first pointed out by Russell,[1] and has recently been reinvestigated by Walter.[2] Neglecting libration, Russell predicted a forward motion of periastron while Walter, taking libration into account, finds that in general the line of apsides should rotate backward, and would advance only when the axial rotation of the components is much faster than their orbital revolution. The latter condition is at variance with ideas now generally held; since, furthermore, the only motions of periastron definitely established are forward motions, it would seem essential to investigate the problem first from an observational point of view.

A search through the known orbits of spectroscopic binaries immediately indicated α Virginis as a promising case for the detection

[1] *M.N.*, **88**, 641, 1928.

[2] *Veröff. Königsberg*, Heft 2 and 3, 33, 1931.

of a change in ω, since (*a*) the orbit possesses a definite eccentricity of about 0.1; (*b*) two spectra are visible; (*c*) the velocity amplitude is large, $K_1+K_2=330$ km/sec.; (*d*) the radii of the components are probably large fractions of the mean distance between their centers; (*e*) the star has been announced as variable in light, which suggests the possibility of obtaining approximate values for the inclination, and the actual dimensions of the system; (*f*) the rotational speed of the brighter component appears to be known with some accuracy; (*g*) a good previous orbit is available, determined by Baker[3] as early as 1908.

Dr. Struve very kindly consented to have the star reobserved at Yerkes Observatory during the 1933/34 season. The 78 spectrograms obtained, as well as 21 secured in 1929/30, have been used by Struve and Ebbighausen for the determination of a preliminary orbit,[4] while in addition many other interesting features of the spectrum have been discussed by them. While it is possible, as has been already pointed out by them, for the curious asymmetry of the lines to produce a spurious orbital eccentricity, the mere fact that the value for ω found by Baker differs 70° from that of Struve and Ebbighausen constitutes sufficient proof that e is real. Owing to the fact that the period is so close to four days, one season is too short to obtain observations over the entire curve; since, moreover, the star is being observed again this season with greater precision, it does not now seem worth while to derive the elements of the orbit with the utmost accuracy. The preliminary orbit by Struve and Ebbighausen suffices to show that there has been no observable change in any element except ω (and hence in T). What concerns us at the present time is the amount of this change in ω, and its mean error.

With e as small as 0.1, it would be useless to employ the usual least-squares formulae, and the following procedure has been adopted.

1. Assuming K, P, and γ to be accurately known, and T and ω to be completely dependent, a least-squares solution was made for e and ω according to the method given by Luyten for κ Pegasi.[5]

[3] *Pub. Allegheny Obs.*, **1**, 65, 1909.

[4] *Ap. J.*, **80**, 365, 1934.

[5] *Ibid.*, **79**, 449, 1934.

2. Using the normal places given by Baker and those by Struve and Ebbighausen, smooth curves were drawn through them; these were read off at twelve points equidistant in phase, and from them the elements were calculated by means of the Wilsing-Russell method of Fourier analysis.[6]

A purist who believes in the rigorous application of least-squares methods to all individual observations might argue that it would have been better to use the normal places themselves for this. Owing to the fact that blends of the lines of the two components render the part of the velocity-curve near the γ-axis practically unobservable, we feel that the procedure followed here is at least as legitimate; it may well lead to results more representative of the actual

TABLE I

LONGITUDE OF PERIASTRON FOR α VIRGINIS

	Original	(1)	(2)
Yerkes 1933.45	40°	50°	52° ± 8°
Allegheny 1908.07	328	323	332 ± 18

conditions, and it is enormously more convenient. The resulting values of ω are given below; only the errors obtained from the Fourier analysis are given, since these are probably the only reliable ones.

The change in ω is clearly established, though its algebraic sign is still ambiguous. If the rotation is *forward*, $\Delta\omega = +80° \pm 20°$; if it is *backward*, $\Delta\omega = 280° \pm 20°$. With $\Delta T = 25.38$ years, these would lead to values for the period U of the apsidal rotation of 114 ± 28 years and 32.6 ± 2.3 years respectively (or of 10,000 times and 2960 times the orbital period P).

In the absence of any other evidence, the shorter period would perhaps be regarded with some suspicion *ipso facto;* but, by a curious coincidence, there exists some slight further information upon this point. In the original article where Wilsing outlined the Fourier-analysis method, he applied it to only one star: α Virginis. Using the 1889 observations of Vogel at Potsdam, he obtained $e = 0.024$,

[6] Wilsing, *A.N.*, **134**, 89, 1933; Russell, *Ap. J.*, **15**, 252, 1904.

$\omega = 266°$. Using the values of ω given above under (2), we calculate for 1889 $\omega = 272 \pm 26°$ if periastron advances, but $\omega = 182° \pm 23°$ if it regresses. The agreement of the former value with that of Wilsing is almost suspiciously close, and while, owing to the manifestly too small value for e obtained by him, these early observations do not merit the weight of the later two series, it is tempting to interpret Wilsing's value as support for an advance of periastron. The question may soon be settled definitely, since if the rotation is backward, $d\omega/dt = -11°$ per year—a quantity easily determinable in a few more years.

For the present we may perhaps adopt a forward motion, and a period of apsidal rotation $U = 10{,}000P$ (order of magnitude).

Before discussing this value in connection with Russell's or Walter's theory, it will be necessary to summarize all other available information on α Virginis. With $K_1 + K_2 = 329$ km/sec., $P = 4.014$ days, $a \sin i$ is found to be 18.06×10^6 km, while the ratio $K_1/K_2 = 0.63$ yields $m_1 \sin^3 i = 8.9\odot$, $m_2 \sin^3 i = 5.7\odot$. Apart from the preliminary announcement by Stebbins[7] and the statement in the annual report of the Dominion Observatory for 1932 and 1933 that the star is under observation at Ottawa, we have seen no data on the possible light-variations. Judging from the spectral class and the resultant low density, the components probably have radii from four to eight times that of the sun, or a sensible fraction of their mutual distance. Since the maximum eclipse can hardly be more than $0^m.2$, the inclination cannot be near 90°. Gaposchkin[8] derives $i = 65°$ and $r_1 = 0.315$, $r_2 = 0.25$ (presumably these are in fractions of the orbital radius), while in another place he gives $i = 75°$, $r_1 = 6\odot$, $r_2 = 5\odot$. For the present we may adopt the approximate values $i = 70°$, giving $a = 19.2 \times 10^6$ km, $m_1 = 10.7\odot$, $m_2 = 6.8\odot$; furthermore, $r_1 = 5 \times 10^6$ km, $r_2 = 4 \times 10^6$ km, hence also $\rho_1 = 0.029\odot$, $\rho_2 = 0.036\odot$—all of which seem reasonable.

From the contours of the lines, which appear dish-shaped for the brighter component but much sharper for the secondary, Struve[9] has derived rotational speeds of 200 and 50 km/sec., respectively,

[7] *Ap. J.*, **39**, 1475, 1916; *Pub. A. A. S.*, **2**, 110, 1920.

[8] *Veröff. Babelsberg*, **9**, Heft 5, 83 and 97, 1932.

[9] *Ap. J.*, **72**, 1, 1930.

the latter value being subject to considerable uncertainty. As Struve has already pointed out, these values are not in agreement with the probable sizes of the stars under the assumption that both stars rotate and revolve in the same period. We do not agree, however, with his conclusion that agreement could be reached by changing the adopted parallax of the system, since then r_1 would become of the order of 12×10^6 km, and hence the stars, even if tidally undeformed, would be practically in contact and deep eclipses might occur.

If the value of 200 km/sec. for the rotational speed of the brighter component is accepted, then the synchronism of rotation and revolution must be abandoned. Even though this is not in accordance with the views now generally held, it would agree qualitatively with Walter's conclusion that periastron can only advance when the axial rotation is faster than the orbital revolution.

With $r_1 = 5 \times 10^6$ km and $v_1 \sin i = 200$ km/sec., we find the period of axial rotation for the brighter component to be $P_1 = 1.7$ days. For the fainter component there is much less certainty. With $r_2 = 4 \times 10^6$ km, and $P_2 = 4.01$ days, $V_2 \sin i$ would be 68 km/sec., which is observationally identical with Struve's value of 50 km/sec. In so far as the observations on the axial rotation and our general ideas of the dimensions of such B stars are concerned, it would be possible for the secondary still to have preserved synchronism between its rotation and revolution, while the primary would appear to revolve in 4 days but rotate in 1.7 days—regardless of how dynamically improbable such a condition might be.

In order to ascertain whether the primary can rotate at the speed observed and still remain stable, we may apply the stability criterion. Using the dimensions adopted above, we find that even if both components were homogeneous they could both rotate in a period of 1.5 days and still remain on the permitted side of the inequality.

Before applying our numerical results, one more effect must at least be considered, viz., the advance of periastron demanded by relativity. Using De Sitter's formula[10] and taking into account the rotation of both components, a rough calculation shows that the

[10] *M.N.*, **76**, 699, 1916.

resulting period of apsidal rotation must be of the order of three thousand years, and hence $\Delta\omega$ for twenty-five years would be only a small fraction of the error of observation. The effect may therefore be neglected here.

In view of the several uncertainties mentioned above, it is not possible to use our findings for a decision between Walter's and Russell's formulae, nor for a determination of the internal density distribution; at best the present data may be used for an analysis of the order of magnitude of some of the effects involved. Putting $r_1/a=\alpha_1$ and $r_2/a=\alpha_2$, Russell's formula, derived by disregarding tidal effects, reads

$$P/U=k_1\varphi_1\alpha_1^2+k_2\varphi_2\alpha_2^2\,, \qquad (a)$$

where φ is the ratio of the centrifugal force to gravity at the equator, e is the ellipticity of a meridian section, and k is given by $k\varphi=e-\varphi/2$. With a rotation period $P_1=1.7$ days for the primary, we have $\varphi_1=\frac{1}{6}$, while $\alpha_1=0.26$. If $P_2=4$ days for the secondary, tidal effects may not be neglected, but φ_2 would be only about $\frac{1}{40}$, and where $\alpha_2=0.21$ the contribution of the secondary to P/U in (a) is considerably less than that of the primary. Since the stars are similar in spectral class, we might set $k_1=k_2$ and then derive a rough value,

$$k=0.008\,,$$

corresponding to an exceedingly high density concentration toward the center.

Disregarding the observed axial rotation of the primary and assuming complete synchronism with tidal control, but neglecting libration, we may apply Russell's extended formula:

$$P/U=k_1\alpha_1^5(1+7m_2/m_1)+k_2\alpha_2^5(1+7m_1/m_2)\,, \qquad (b)$$

which, when again putting $k_1=k_2$, yields $k=0.009$—again indicating a very high density concentration.

If, on the other hand, we use Walter's formula (still assuming synchronism, but taking libration into account), we must necessarily choose the alternative offered by the observed $\Delta\omega$, i.e., a backward motion of periastron, and hence $P/U'=1/2960$. With Walter's

expression for $\lambda_a - 1$ as measuring the regression of periastron according to equation (16) in his second paper, we have

$$\lambda_a - 1 = P/U' = 3\mu/10a^2 . \; [r_1^2(3\epsilon_1^2 - \epsilon_1'^2) + r_2^2(3\epsilon_2^2 - \epsilon_2'^2] , \qquad (c)$$

where ϵ, ϵ' are, respectively, the eccentricities of the equatorial and meridional sections of the components and μ expresses the ratio of the moments of inertia of the stars to those of homogeneous spheres of equal size and mass (strictly speaking, we should again use two different values, μ_1 and μ_2, for the two components, but in first approximation these may be equal). By virtue of equations (3) in Walter's first paper we have

$$3\epsilon_1^2 - \epsilon_1'^2 = C_1' . \; (5m_2 - m_1)/(m_1 + m_2) = \tfrac{2}{3} \cdot (r_1/a)^3 \cdot (5m_2/m_1 - 1) ,$$

if we have correctly interpreted the numerical value of his constant C_1'. Substituting this in (c), we finally obtain

$$P/U' = \mu a_1^5 (m_2/m_1 - 0.2) + \mu a_2^5 (m_1/m_2 - 0.2) . \qquad (d)$$

With the numerical values above we then find

$$\mu = 0.3 ,$$

which would correspond to a value of k in Russell's notation, of 0.11, or to a central condensation about equal to that of Saturn.

While this last value conforms better to our present ideas about density concentration in stars, it has been derived only by disregarding one of the salient facts of observation; the other two values derived for k are likewise subject to considerable limitation in the assumptions involved.

Summing up, therefore, we might say that perhaps the chief result of the present analysis is the manifest uncertainty existing in many points of the problem of apsidal motion, and in the determination of stellar density concentration. Before a satisfactory theory can be established it would seem essential that observations be obtained of the advance or regression of periastron in a large number of binaries with, preferably, considerable range in spectral class, mass, dimension, and density.

MINNEAPOLIS, MINN.
December 1, 1934

THE SPECTRUM OF R AQUARII, 1919–1934*

By PAUL W. MERRILL

ABSTRACT

R Aquarii, type M7e, period 387 days, has been known as a variable since 1811. Lines characteristic of gaseous nebulae were photographed in its spectrum at Mount Wilson in October, 1919. Moreover, later spectrograms showed at times a peculiar high-temperature "companion" spectrum marked by bright lines of *H*, *He*, and *Fe*.

The red long-period variable.—Numerous detailed data on line intensities and displacements show the spectral features and their cyclic changes to be characteristic of long-period variables.

The nebular spectrum.—The lines λλ 5007, 4959, 4363 were conspicuous from 1919 to 1925, but thereafter decreased in intensity until from 1928 to 1934 they were very weak. The relative intensity of λ 4363 was greater than that characteristic of planetary nebulae, probably indicating higher pressure. Lines of *H*, *He*, [*Ne* III], and the unidentified line λ 4658 were apparently associated with the nebular spectrum, but the behavior of [*S* II] lines resembled that of lines of [*Fe* II]. Data on displacements reveal discordances larger than errors of measurement. In general, the values tend to become algebraically smaller during the period of observation.

Spectrum of the companion.—The spectrum of the hypothetical "companion" first appeared in 1922, and is present on most of the subsequent spectrograms. For a time the spectrum resembled that of the nucleus of a planetary nebula, type Ofp, but later the continuous spectrum became stronger, with numerous bright lines of enhanced iron, type Bep. In 1934 the continuous spectrum was very weak, and forbidden lines of ionized iron were dominant. Numerous details are given.

Discussion.—Spectroscopic data make possible a partial analysis of the light-curve into two curves: one for the Me star and the other for the companion (Fig. 2.)

The displacements of the bright lines in the spectrum of the companion appear to be approximately the same as those of the bright lines of the Me star. The displacements of the nebular lines exhibit remarkable irregularities.

Similarities between some phases of the spectrum of R Aquarii and spectral features of certain other variables are pointed out, and it is suggested that factors of general astrophysical interest may lie back of the observed phenomena.

The outer nebulosity should be carefully observed.

HISTORICAL

The brightness of R Aquarii[1] was discovered to vary by Harding in 1811, and the fluctuations were soon found to have a period of about 387 days. This period has been maintained without marked alteration until recent years. The light-curve has been distinguished by narrow maxima and broad, flat minima.[2] The magnitude at maximum has normally varied from 6.0 to 8.5, while the minimum mag-

* *Contributions from the Mount Wilson Observatory, Carnegie Institution of Washington*, No. 513.

[1] HD 222800: R.A. 23^h38^m6, Dec. $-15°50'$, 1900.

[2] Leon Campbell, *Harvard Ann.*, **57**, 206, 1907; also *Harvard Reprint*, No. 21, 1920.

nitude has, until 1928, not deviated greatly from 10.3.[3] A detailed study of the light-curve is being made at the Harvard College Observatory.

The spectrum was classified at Harvard as Md (later M6e)—a type quite normal for a red variable of period 387 days.

MOUNT WILSON SPECTROSCOPIC OBSERVATIONS

Spectrograms of R Aquarii obtained at Mount Wilson in October, 1919, disclosed, in addition to a normal spectrum of class M7e, several conspicuous emission lines characteristic of gaseous nebulae. During the following year photographs of this most unusual combination of spectral features showed that the nebular lines, instead of sharing the changes of intensity exhibited by the spectrum of the variable star as the magnitude rose and fell in the regular light-cycle, remained of approximately constant intensity. In later years, however, the nebular lines became fainter and at times practically disappeared, but no connection has been traced between their intensities and the brightness of the red variable. Moreover, a third spectrum totally different from the other two appeared in 1922 and at times during the past few years has been dominant. This spectrum, a peculiar high-temperature one marked by bright lines of hydrogen, helium, and iron, has exhibited radical changes over a period of years.

It will therefore be convenient to discuss the spectroscopic observations as if R Aquarii consisted of three light-sources, all variable, viz.:

	Type
1. A red long-period variable	M7e
2. A gaseous nebula	P
3. A blue "companion"	Ofp or Bep

To avoid misunderstanding, however, it may be well to remark that the three spectra have always *appeared* to originate in a single stellar object.[4] Judgment concerning the physical relationship of the three

[3] The relatively small range as well as the broad flat minima of nearly constant magnitude may be attributed to the light of a hypothetical companion star. See later discussion.

[4] P. W. Merrill, *Pub. A.S.P.*, **31**, 305, 1919; W. H. Wright, *ibid.*, p. 309. There is a possible exception: a minute nebula surrounding the star, photographed at Lowell

sources must therefore be based chiefly on the interpretation of the spectrograms.

The Mount Wilson spectrograms are listed in Table I. The photometric data were kindly supplied by the Harvard College Observatory. The phase is reckoned in days from maximum. Estimated intensities of the continuous spectrum due to the M-type variable (V) and to the companion (C) at λ 4900 and at λ 4200 are included in the table, and in the last column the intensities of the nebular lines λ 5007 and λ 4959 are indicated by symbols: "A," outstanding; "B," intermediate intensity; "C," weak; "D," not seen.

SPECTRUM OF THE RED LONG-PERIOD VARIABLE

The spectrum of the M-type variable, as indicated in Table I, appears well exposed and without interference from that of the companion upon relatively few of the Mount Wilson spectrograms. This is due largely to the fact that the red variable was decidedly brighter than the companion during but little of the time since 1919, when the object was sufficiently far from the sun for spectrographic observation. Data concerning displacements of the dark lines in the M-type spectrum are therefore meager. The bright lines belonging to the M spectrum, λλ 4202, 4308, and 4571, however, suffered less interference from the other sources and a considerable number of observations are available.

The dark-line spectrum, shown in great detail on several spectrograms (see Pl. III of *Contr.* No. 206),[5] conforms very closely indeed to the Me spectrum characteristic of normal red variables of periods 300–400 days. The rich line-spectrum, classified M7e, differs in no important respects from that of *o* Ceti, M6e, on one hand, or from that of R Leonis, M8e, on the other.

Velocities derived from measurements of the dark lines are in Table II. The values from the γ plates (taken with the 60-in. telescope) are algebraically less than those from the C plates (100-in.

Observatory (C. O. Lampland, *Pop. Astr.*, **30**, 619, 1922) and at Mount Wilson, may have contributed to the nebular lines. The peculiar outer lenticular nebulosity discovered by Lampland (*ibid.*, p. 162) is too faint to have affected the spectrograms described in this contribution.

[5] *Ap. J.*, **53**, 375, 1921.

TABLE I

JOURNAL OF OBSERVATIONS

	Plate	Date	J.D. 2420000 +	Phase Days	Mag.	Contin. Spect. λ 4900 V	Contin. Spect. λ 4900 C	Contin. Spect. λ 4200 V	Contin. Spect. λ 4200 C	Neb. Lines
C	136	1919 Oct. 16	2248	− 44	8.4	4	o	tr	o	A
	141	17	2249	− 43	8.4	6	o	3	o	A
	152	19	2251	− 41	8.3	7	o	4	o	A
	157	Nov. 1	2264	− 28	7.7	10	o	5	o	A−
	182	7	2270	− 22	7.4	3	o	tr	o	B
	191	9	2272	− 20	7.3	4	o	tr	o	B
γ	8870	13	2276	− 16	7.2	10	o	3	o	B
	8871	13	2276	− 16	7.2	4	o	tr	o	B
	8877	14	2277	− 15	7.2	6	o	1	o	B
	8892	Dec. 8	2301	+ 09	6.9	3	o	tr	o	?
	8912	10	2303	+ 11	6.9	7	o	4	o	B
	8926	14	2307	+ 15	6.9	7	o	4	o	B
C	236	1920 Jan. 9	2333	+ 41	7.4	o	o	o	o	?
	239	10	2334	+ 42	7.4	o	o	o	o	?
	240	11	2335	+ 43	7.4	2	o	o	o	B
	255	16	2340	+ 48	7.6	1	o	o	o	B
	456	June 1	2477	+185	9.8	o	o	o	o	A
	526	July 6	2512	+220	10.0	o	o	o	o	A
	535*	8	2514	+222	10.0	o	o	o	o	A
	560	29	2535	+243	10.2	o	o	o	o	A
	614	Aug. 27	2564	+272	10.2	o	o	o	o	A
	637	Sept. 2	2570	+278	10.2	tr	o	o	o	A
	646	4	2572	+280	10.2	o	o	o	o	A
	687	Oct. 2	2600	− 81	9.9	1	o	o	o	A
	814	Dec. 26	2685	+ 04	6.7	2	o	o	o	B−
	1056*	1921 June 19	2860	+179	10.0	tr	o	o	o	A
	1205*	Aug. 13	2915	+234	10.2	1	o	o	o	A
	1391	Oct. 11	2974	− 98	9.5	tr	o	o	o	A
	1394	12	2975	− 97	9.5	o	o	o	o	A
	1453	Nov. 13	3007	− 65	9.0	5	o	tr	o	A
	1498	Dec. 15	3039	− 33	7.8	15	o	3	o	B
	1827	1922 Aug. 10	3277	+205	9.6	o	3	o	o	A
	1933	Oct. 7	3335	−123	9.2	o	o	o	o	A
	2058	1923 Jan. 6	3426	− 32	7.5	1	o	o	o	B
	2343	July 3	3604	+156	9.2	o	o	o	o	A
	2412*	Aug. 30	3662	+204	9.2	1	3	o	tr	A
	2416	31	3663	+205	9.2	o	tr	o	o	A
	2439	Sept. 6	3669	+211	9.2	o	2	o	tr	A
	2517	Oct. 28	3721	−120	9.0	o	tr	o	o	A
	2898	1924 July 20	3987	+146	9.4	tr	o	o	o	A
	2926*	Aug. 9	4007	+166	9.9	5	o	tr	o	A

* Single-prism spectrograph and 10-inch camera, dispersion at $H\gamma$ about 65 A/mm. The dispersion of all other plates is about 35 A/mm at $H\gamma$. All except V 522 were taken with a single-prism spectrograph and 18-inch camera. V 522 was taken with the "ultra-violet" three-prism instrument and 10-inch camera. Nearly all the spectrograms are of the usual blue-violet spectral region. The emulsions employed, with few exceptions, were: 1919–1924, Seed 30; 1925–1933, Eastman 40; 1934, Imperial Eclipse Special. The C and V plates were obtained with the 100-inch telescope; the γ plates with the 60-inch.

TABLE I—*Continued*

Plate	Date	J.D. 2420000 +	Phase Days	Mag.	Contin. Spect.				Neb. Lines
					λ 4900		λ 4200		
					V	C	V	C	
3020	1924 Sept. 16	4045	+204	10.5	0	0	0	0	A
3379*	1925 July 5	4387	+157	9.4	5	0	tr	0	A
3542	Oct. 1	4425	+195	10.2	tr	tr	0	0	A
3908	1926 July 29	4721	+ 99	9.5	3	0	0	0	B
4019*	Sept. 18	4777	+155	10.0	3	0	0	0	B
4125*	Dec. 13	4863	+241	8.8	0	7	0	4	C−
4138	16	4866	+244	8.8	0	4	0	1	C
4155*	1927 Jan. 14	4890	−118	9.0	tr	5	0	2	C
4322	June 22	5054	+ 46	7.7	4	0	2	0	D
4359*	July 14	5076	+ 68	8.1	8	0	3	0	C
4414*	Sept. 8	5132	+124	9.2	2	0	tr	0	B
4472*	Oct. 12	5166	+158	9.6	4	1	tr	0	B
4590*	Dec. 23	5238	+230	9.8	2	1	tr	tr	B
4863	1928 June 27	5425	+ 50	7.3	2	0	0	0	D
4959	Aug. 29	5488	+113	8.5	2	4	1	2	C
5022*	Oct. 4	5524	+149	8.8	1	4	0	1	C
5065	Nov. 20	5571	+196	9.0	0	tr	0	0	C
5099	Dec. 21	5602	+227	8.8	tr	2	0	tr	C
5241	1929 July 17	5810	+ 89	8.7	tr	0	0	0	?
5245*	18	5811	+ 90	8.7	3	1	tr	tr	B−
5264*	Aug. 15	5839	+118	9.0	1	3	tr	1	B
5356*	Nov. 22	5938	+217	8.8	0	3	0	1	C
5376	Dec. 14	5960	−127	8.7	0	3	0	1	C
5484	1930 June 14	6142	+ 55	8.0	1	tr	0	0	D
5496	July 9	6167	+ 80	8.3	1	tr	0	0	C
5547	Sept. 10	6230	+143	8.6	0	1	0	0	C
5551	11	6231	+144	8.6	0	3	0	tr	C
5641	Dec. 4	6315	+228	9.0	0	3	0	1	C−
5829	1931 Aug. 31	6585	+ 75	8.5	1	2	0	0	C−
5854	Oct. 1	6616	+116	8.9	tr	3	0	1	D
γ 18954*	1932 July 21	6910	00	7.9	2	7	0	4	D
C 6096	Aug. 17	6937	+ 27	8.0	tr	2	0	tr	C−
6154	Oct. 11	6992	+ 82	8.3	0	3	0	1	C
6306	1933 Sept. 7	7323	+ 23	7.2	2	4	0	3	D
6321	Oct. 6	7352	+ 52	7.3	1	5	0	2	D
6467*	1934 July 21	7640	− 57	10.1	1	0	tr	0	D
6495*	28	7647	− 50	10.0	2	0	tr	0	C
6500	29	7648	− 49	10.0	1	0	0	0	C
V 522	Aug. 1	7651	− 46	9.9	1	0	1	0	D
C 6533	30	7680	− 17	9.3	5	0	2	0	C−
6557	Sept. 28	7709	+ 12	9.3	4	0	2	0	D
6578	Oct. 25	7736	+ 39	9.6	4	0	2	0	C−
6586*	Nov. 21	7763	+ 66	10.1	4	0	3	0	C

telescope), as had been previously noticed for another southern variable, R Hydrae.[6] The differences between the displacements of bright and dark lines, column 4, are fairly consistent, with a mean value of +13.4 km/sec. Because most of the spectrograms are with the 100-inch telescope, it may be better for comparison with other data to adopt for the dark-line velocity the mean of the four determinations from C plates, −14.5 km/sec. Bright hydrogen lines are present on all the spectrograms, but their study is complicated by the fact that they may originate in any one of the three sources. On

TABLE II

VELOCITIES FROM ABSORPTION LINES OF M-TYPE SPECTRUM

Plate	Rad. V	No. Lines	Abs.− Em.
C 141	−17.3	48	.....
C 152	16.3	42	.....
C 157	9.6	39	+ 9.8
γ 8870	24.0	25	15.8
γ 8912	23.2	17	12.1
γ 8926	28.1	33	14.7
C 1498	−14.8	16	+14.6
Mean	.....	.....	+13.4

about ten plates taken when the red variable was near its maximum magnitude, the bright *Hγ* and *Hδ* lines of the variable are clearly dominant. On these plates the intensities of these lines relative to each other and to the continuous spectrum are characteristic of Me variables.[7]

The bright lines λ 4202 *Fe* I, λ 4308 *Fe* I, and λ 4571 *Mg* I, emitted by the red variable, are not interfered with by lines from the other sources, and have been observed throughout a considerable portion of the light-cycle. Their relative intensities were estimated in exactly the same way as was done for several typical Me variables. The intensity ratio λ 4308:4202 when plotted in Figure 11 of *Contr.* No. 399[7] gives a curve parallel to those for R Hydrae, χ Cygni, R Leonis, and U Orionis, at an intermediate position, just above the curve for

[6] *Mt. W. Contr.*, No. 399, p. 39; *Ap. J.*, **71**, 323, 1930.

[7] *Mt. W. Contr.*, No. 399; *Ap. J.*, **71**, 285, 1930.

R Leonis. The plotted intensity ratio λ 4571:4308 resembles the curves for U Orionis and R Hydrae (Fig. 13).

Displacements of the bright lines of the red variable measured from C plates are summarized in Table III. The mean value from five lines is −29.5 km/sec., differing from the adopted value for the displacement of the absorption lines by 15.0 km/sec. This difference is in reasonable agreement with the value (Table II) measured directly on five individual plates, and with that previously adopted.[8] Nor does it differ appreciably from the mean value for type M7e taken from Table VII of *Contr.* No. 264, or that from the curve in Figure 2, in the same paper, for period 387 days.

TABLE III

VELOCITIES FROM EMISSION LINES OF THE Me SPECTRUM

Line	Rad. V	No. Plates
$H\gamma$	−30.9 km/sec.	12
$H\delta$	29.4	8
λ 4202	30.0	16
4308	29.3	20
4571	−28.1	20
Mean	−29.5	.....

THE NEBULAR SPECTRUM

The nebular lines λλ 5007, 4959, and 4363 were conspicuous on the first Mount Wilson spectrogram of R Aquarii, taken on October 16, 1919, when the apparent magnitude of the variable was 8.3. During the next few weeks the magnitude rose to 6.9, and by the following summer it had declined to 10.5, with corresponding changes in the intensity of the Me spectrum. During this interval the nebular lines retained approximately their original intensities, but in later years they have become decidedly fainter. On many plates, especially among those taken since 1925, the lines have but a fraction of the original intensities, and on a few plates cannot be seen at all. An idea of the course of these changes may perhaps be gained from the reproductions in Plate III (see also Pl. III of *Contr.* No. 206)[5] and from

[8] Table VI of *Mt. W. Contr.*, No. 264; *Ap. J.*, **58**, 215, 1923.

Table I, last column, where the intensity of the chief nebular lines with respect to neighboring continuous spectrum is indicated by the letters "A"–"D" (see p. 314). The lines appear sharp, being monochromatic as far as can be determined with the dispersion employed.

Unfortunately, not much can be ascertained concerning the earlier history of the nebular lines. The Harvard objective-prism plates probably would not reveal the presence of the nebular lines except when the Me spectrum was faint. Concerning two plates in the Harvard collection, Miss Cannon has made the following remarks:[9]

1893 Oct. 17. Phase +110 days, spectrum P: Faint nebular band 5007, and bright hydrogen lines $H\beta$–$H\zeta$ visible, with no trace of the M spectrum

1908 Oct. 26. Phase +229 days, spectrum P: A very faint image shows only bright lines, $H\gamma$ being strongest

As far as can be judged by inspection of the Mount Wilson spectrograms, *relative* intensities of the three nebular lines of [*O* III], λλ 5007, 4959, 4363, remained constant; any apparent variations are probably within the range of photographic effects. This is particularly interesting because, as compared with these lines in the spectra of planetary nebulae, λ 4363 is unusually strong; in fact, the ratio of its intensity to that of λ 4959 is equaled or exceeded by only one nebula in Wright's list,[10] IC 4997.

The intensity of the hydrogen lines relative to those of [*O* III] is comparable to that exhibited by several planetary nebulae. On the earlier spectrograms the intensity of the nebular $H\beta$ line is nearly equal to that of λ 4959. On spectrogram C 1827, however, as well as on most of the subsequent plates, $H\beta$ is much stronger, probably because of the hydrogen emission of the companion.

Bright lines of neutral helium are often present in low intensity. λ 4471 is perhaps one-fourth as strong as λ 4363. λ 4686 of *He* II is not seen with certainty in the nebular spectrum. Lines both of neutral and of ionized helium appeared at times in the spectrum of the companion.

The ultra-violet pair, λλ 3869, 3968, now ascribed to [*Ne* III], is a feature of the nebular spectrum. The line of shorter wave-length, λ 3869, was first observed by Dr. J. H. Moore[11] at Lick Observatory

[9] "Harvard Catalogue of Long-Period Variable Stars," *Harvard Ann.*, **79**, 205, 1928.

[10] *Pub. Lick Obs.*, **13**, 193, 1928.

[11] *Pub. A.S.P.*, **31**, 309, 1919.

at a time when the spectrum of the red variable was strong. The absence of the companion line λ 3968 was ascribed by Dr. W. H. Wright[12] to the blanketing effect of absorption in the calcium line H in the spectrum of the variable. The Mount Wilson data on the neon pair are extremely meager, as in this spectral region the transmission of the spectrographs with which most of the observations were made is low. Both lines are present, however, on plates C 1205 and C 2926, on which the nebular spectrum is strong, while on C 141, λ 3869 is visible with a doubtful trace of λ 3968. On three rather poor plates taken with a trial low-dispersion slit spectrograph on August 19, 20, and November 17, 1925, λ 3869 is present, while λ 3968 appears to be blended with $H\epsilon$. This is true also on small-scale slitless spectrograms obtained by Hubble on August 24, 1922, and on July 16, 1933.

λ 4658 is a well-marked line on C 2926, and is present on a number of other plates taken from 1919 to 1926 inclusive. On C 2926 it is probably accompanied by λλ 4701, 4733.[13] On this plate the nebular lines as a whole are strong, λλ 5007, 4959, 4363 being very intense. $H\beta$ is also very intense, but the Balmer decrement is extremely rapid, $H\epsilon$ being very weak although clearly visible. The [*Ne* III] lines λλ 3869, 3968 (which are not visible on many of the Mount Wilson plates) are somewhat stronger than $H\epsilon$.

The nebular line λ 4068 [*S* II] appears in low intensity on several spectrograms taken during the years 1921–1929; it is prominent on the 1934 plates, being accompanied by the companion line λ 4076. Its behavior seems to have little in common with that of the other nebular lines but to resemble strongly that of the forbidden iron lines. On several plates a close companion line was measured at 4069.9 A.

Measured displacements of the more important nebular lines are summarized in Table IV. The system of weighting assigns unit weight to the measurement of a good line on a plate taken with the 18-inch camera, weight 0.5 to a poor line or to one on a plate with the 10-inch camera. The hydrogen lines whose displacements are recorded in Table IV are, in many instances, blends of lines from more than one source. Lines in which the contribution of the bright lines associated with the Me variable appears to be dominant are included

[12] *Ibid.*

[13] *Mt. W. Contr.*, No. 349; *Ap. J.*, **67**, 179, 1928.

in Table III, but omitted from Table IV. The values for N1 and N2 (λλ 5007, 4959) show a progression from about zero during the early years to about −70 km/sec. after 1930, which can scarcely be ascribed to errors of measurement.[14] The early values for λ 4363 are about −20 km/sec. instead of zero as for N1, 2, but the later ones tend to be algebraically smaller. The displacements of the hydrogen

TABLE IV

VELOCITIES FROM EMISSION LINES (KM/SEC.) AND WEIGHTS

Year	N1, 2		λ 4363		*Hβ*		*Hγ*		*Hδ*		*He*		λ 4658		*Fe* II		[*Fe* II]	
1919....	A*	+ 6	8.5	−21	3.5	− 4	4.5	−16	3	....	....	− 7	1	− 8	2	....	....	....	....
1920....	A	− 6	8.5	23	5	14	5.5	11	6	....	....	11	2.5	3	1	....	....	....	....
1921....	A	+ 5	4	20	2	21	2.5	16	2	....	....	24	1.5	6	0.5	....	....	....	....
1922....	A	+ 1	2	23	1	23	2.5	16	1	−13	0.5	20	1.5	6	1	....	....	....	....
1923....	A	−14	8.5	33	4.5	30	3.5	30	4.5	32	2	28	5.5	31	1	−41	7	−30	2
1924....	A	−21	4.2	35	2.5	25	2.5	30	2.5	30	2.5	22	3	26	2	....	....	28	4
1925....	A	−27	3	26	1.5	28	1.5	21	1.5	27	0.5	35	1	15	0.5	....	....	....	....
1926†...	B	−35	3	37	0.8	21	1.5	11	1.5	3	0.5	4	0.5	− 6	0.2	....	....	....	....
1926‡...	C	+19	2	....	....	14	1.5	35	2	30	2	37	1	....	....	40	21	....	....
1927....	B	+40	1	....	....	7	3	1	1.5	1	1.5	15	1.5	....	....	23	3	32	5
1928....	C	− 4	2.2	....	....	26	4.5	24	3.5	28	3.5	34	5	....	....	33	38	30	7
1929....	C	−47	1.8	60	1.2	38	3	43	3.5	36	3.5	34	3	....	....	33	17	47	2
1930....	C	−37	0.6	64	0.2	30	4	32	4	33	5	29	4	....	....	32	26	....	....
1931....	C	−76	0.5	....	....	19	2	31	2	30	2	21	1	....	....	34	20	....	....
1932....	C	−69	2	−53	1	−30	2.5	36	2.5	30	2.5	25	3.5	....	....	29	21	36	1
1933....	D	....	....	....	....	+12	2	23	2	37	2	0	2	....	....	30	20	....	....
1934....	C	−64	2	....	....	−22	6.5	−23	6.5	−27	6.5	−11	0.5	....	....	−24	23	−35	65
Mean	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	−31.8	....	−34.6	....

* Intensities of the nebular lines (see p. 314).

† July and September.

‡ December, 1926, and January, 1927.

lines decrease algebraically after 1920. After 1926 these lines belong to the companion spectrum rather than to that of the nebula. The displacements of λ 4658.08, although having small weight, appear to be algebraically smaller in 1923–1925 than in 1919–1922. The determination in 1926 is very poor.

SPECTRUM OF THE COMPANION

The so-called companion spectrum first appeared in 1922, and on most of the subsequent spectrograms has been seen either alone or blended with the M-type spectrum. The estimated intensity of the

[14] On account of the unfavorable position of these lines at the end of the spectral region for which the spectrograph was usually adjusted, the accuracy of observation is not so great as for lines of shorter wave-length, but errors large enough to account for the apparent changes in the displacements of N1 and N2 are by no means to be expected.

continuous spectrum of the companion and of the M spectrum at λ 4900 and at λ 4200 on the various spectrograms is indicated in Table I. The intensity of the M spectrum at λ 4900 was judged from the titanium band-heads near $H\beta$; at λ 4200 several absorption lines, particularly *Ca* λ 4227, were used. Zero indicates that the continuous spectrum is not seen; "tr," a trace; 5, a fairly strong exposure. These

TABLE V

COMPANION SPECTRUM IN 1923; EMISSION LINES
C 2412; August 30, 1923

I.A. Lab.	El.	Int.	I.A. Lab.	El.	Int.
3889.05	*Hζ*	tr	4555.90	*Fe* II	tr
3970.08	*Hε*	0.5	4571.11	*Mg* I*	1
4068.62	[*S* II]	tr?	4583.84	*Fe* II	1
4101.74	*Hδ*	3	4629.33	*Fe* II?	0.5
4202.03	*Fe* I*	tr	4634.16	*N* III	0.5n
4267.02	*C* II	0.5n	4640.64	*N* III	1n
4267.27	*C* II		4641.90	*N* III	
4287.40	[*Fe* II]	0.5	4647.40	*C* III	
4307.91	*Fe* I*	0.5	4650.16	*C* III	2n
4340.47	*Hγ*	7	4651.35	*C* III	
4351.77	*Fe* II	0.5	4658.08	Neb	1
4363.21	[*O* III]	4	4685.81	*He* II	3n
4387.93	*He* I	2n	4701.5	Neb	tr
4413.79	[*Fe* II]	0.5	4713.14	*He* I	2
4416.81	*Fe* II	0.5	4728.09	[*Fe* II]?	0.5
4416.28	[*Fe* II]		4861.33	*Hβ*	14
4471.48	*He* I	4	4921.93	*He* I	3(n)
4481.22	*Mg* II	1n	4923.92	*Fe* II	
4508.29	*Fe* II	tr	4958.91	[*O* III]	5
4515.34	*Fe* II	tr	5006.84	[*O* III]	10
4520.24	*Fe* II	tr	5015.68	*He* I	(1)
4522.64	*Fe* II	tr	5018.44	*Fe* II	(1)
4549.48	*Fe* II	0.5			

* Associated with the Me spectrum.

slit spectrograms of an object far from the zenith are not suitable for spectrophotometric measurements. About all that can be said concerning the continuous spectrum of the companion is that it appears to be that of a high-temperature source. Numerous emission lines are present, the most prominent of which are those of hydrogen and enhanced iron. No absorption lines have been noted except, on a few occasions, P Cygni-type components on the violet sides of bright hydrogen and helium lines.

In 1922 and 1923, during the periods when the red variable was

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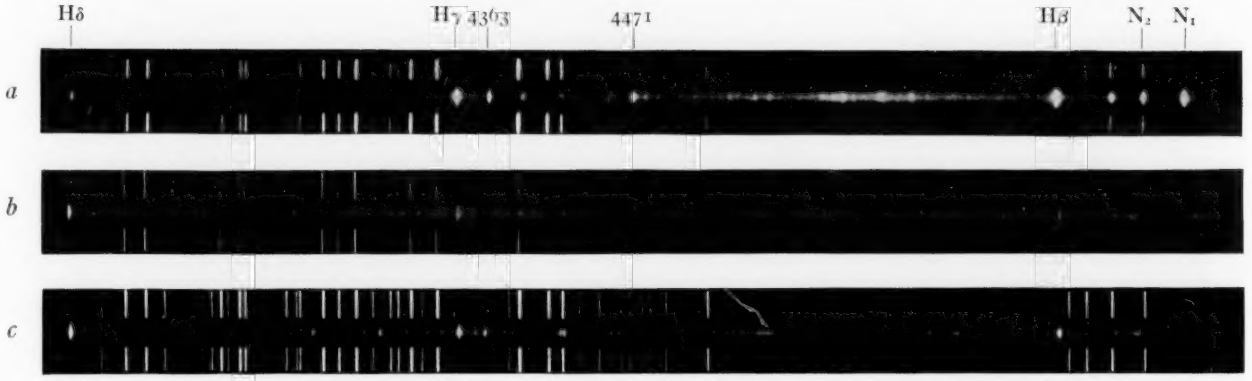
PLATE III



VARIOUS PHASES OF THE SPECTRUM OF R AQUARII

a) C 2412, 1923 August 30—type Ofp+P; *b*) C 6321, 1933 October 6—type Bep; *c*) C 6578, 1934 October 25—"1934 stage," showing forbidden lines of ionized iron. See also Pl. III, *Mt. W. Contr.*, No. 206; *Ap. J.*, **53**, 375, 1921.

faint, the spectrum as a whole bore a general resemblance to that of a planetary nebula and its nucleus. The spectrum of the companion exhibited numerous slightly diffuse emission lines, a number of which

TABLE VI

COMPANION SPECTRUM IN 1933; EMISSION LINES
C 6321; October 6, 1933

I.A. Lab.	El.	Int.	I.A. Lab.	El.	Int.
3889.05	*H*ζ	0.5	4443.80	*Ti* II	0.5
3970.08	*He*	1	4468.50	*Ti* II?	tr
4026.19	*He* I†	tr	4471.48	*He* I†	1
4101.74	*H*δ†	4	4481.22	*Mg* II	1
4102.95	*Si* I?*	0.5	4489.21	*Fe* II	0.5
4122.67	*Fe* II	tr	4491.41	*Fe* II	0.5
4173.48	*Fe* II	1	4501.27	*Ti* II	tr
4178.87	*Fe* II	1	4508.29	*Fe* II	1
4202.03	*Fe* I*	1	4515.34	*Fe* II	1
4233.16	*Fe* II	?	4520.24	*Fe* II	1
4258.16	*Fe* II	tr	4522.64	*Fe* II	1
4273.31	*Fe* II	tr	4529.18	*Al* III	tr
4287.40	[*Fe* II]	tr	4528.91	*Al* III	
4290.23	*Ti* II	tr	4534.17	*Fe* II	0.5
4296.56	*Fe* II	tr	4533.97	*Ti* II	
4300.05	*Ti* II	tr	4541.52	*Fe* II	0.5
4303.18	*Fe* II	1	4549.48	*Fe* II	1
4307.89	*Ti* II	1	4549.64	*Ti* II	
4307.91	*Fe* I*		4555.90	*Fe* II	0.5
4312.88	*Ti* II	1	4576.31	*Fe* II	tr
4314.09	*Sc* II		4583.84	*Fe* II	2
4314.98	*Ti* II		4629.33	*Fe* II	1
4340.47	*H*γ†	7	4666.75	*Fe* II	tr
4351.77	*Fe* II	1	4713.14	*He* I	tr
4358.38	[*Fe* II]	tr	4731.49	*Fe* II	tr
4374.46	*Sc* II?	0.5	4824.14	*Cr* II	tr
4375.93	*Fe* I?*		4861.33	*H*β†	10
4385.39	*Fe* II	1	4923.92	*Fe* II	1
4395.04	*Ti* II	1	5018.44	*Fe* II	1
4399.78	*Ti* II	0.5	5197.56	*Fe* II	tr
4416.81	*Fe* II	1	5234.62	*Fe* II	tr

* Associated with the Me spectrum.
† Absorption of the P Cygni type is present on the violet side.

corresponded to features in the nuclei of several planetary nebulae, e.g., that of NGC 6572, as described by W. H. Wright. The most appropriate classification symbol might be Ofp. Plate C 2412, August 30, 1923, illustrated in Plate III and described in Table V, may be taken as typical of the epoch under discussion. The wave-lengths in Tables V, VI, and VII are, instead of the measured values, those

generally adopted for the lines in question. The lines marked "n" are conspicuously hazy.

During 1924 and 1925 no further striking spectral developments were noted, although the magnitude of the companion seemed to be lower than in 1923. In July and September, 1926, the nebular lines

TABLE VII

FORBIDDEN LINE SPECTRUM IN 1934; EMISSION LINES
C 6578; October 25, 1934

I.A. Lab.	El.	Int.	I.A. Lab.	El.	Int.
3889.05	*Hζ*	1	4474.90	[*Fe* II]	tr
3905.51	*Si* I*	tr	4488.77	[*Fe* II]	0.5
3933.67	*Ca* II	tr	4492.05	[*Fe* II] ?	0.5
4068.62	[*S* II]	2	4491.41	*Fe* II ?	
4069		1	4508.29	*Fe* II	tr
4076.22	[*S* II]	tr	4514.92	[*Fe* II]	0.5
4101.74	*Hδ*	7	4515.34	*Fe* II	
4102.95	*Si* I*	1	4549.48	*Fe* II	0.5
4122.67	*Fe* II	tr	4549.64	*Ti* II?	
4178.87	*Fe* II	0.5	4555.90	*Fe* II	tr
4202.03	*Fe* I*	1?	4558.66	*Cr* II	?
4233.16	*Fe* II	1	4571.11	*Mg* I?*	?
4243.95	[*Fe* II]	2	4583.84	*Fe* II?	?
4276.87	[*Fe* II]	2	4629.33	*Fe* II	1
4287.40	[*Fe* II]	3	4639.69	[*Fe* II]	1
4319.64	[*Fe* II]	2	4728.09	[*Fe* II]	1
4340.47	*Hγ*	5	4774.74	[*Fe* II]	0.5
4351.77	*Fe* II	1	4814.55	[*Fe* II]	1
4352.80	[*Fe* II]		4848.27	*Cr* II?	0.5
4358.38	[*Fe* II]	1	4861.33	*Hβ*	7
4359.34	[*Fe* II]	2	4889.66	[*Fe* II]	0.5
4413.79	[*Fe* II]	2	4923.92	*Fe* II	0.5
4416.28	[*Fe* II]	2	5006.84	[*O* III]	tr
4452.09	[*Fe* II]	1	5018.44	*Fe* II	0.5
4457.96	[*Fe* II]	1	5158.05	[*Fe* II]	0.5

* Associated with the Me spectrum.

and the companion spectrum seemed particularly weak. By December a striking transformation had taken place: the continuous spectrum of the companion was then much stronger than at any previous time during the Mount Wilson observations, and the general character of the spectral features was different from anything previously seen on our plates. The bright hydrogen lines had broad dark companions on their violet sides, as in P Cygni, and numerous bright lines due chiefly to ionized iron (permitted lines only) were promi-

nent. The nebular lines λ 4959 and λ 5007, although still present, were relatively inconspicuous.

In 1927 the continuous spectrum was much weaker and the features were more like those seen in 1922 and 1923, but the forbidden iron lines were somewhat stronger, the nebular lines much weaker.

In 1928 the companion spectrum returned to the appearance it had shown for the first time in December, 1926, and for the six-year interval ending with 1933 exhibited only minor variations. Throughout this period all the companion lines were slightly diffuse, although not of great width. Most of them were of moderate intensity compared to the continuous spectrum. Plate C 6321, October 6, 1933, described in Table VI, is typical of this epoch.

In July, 1934, the combined light of the Me variable and the companion was fainter than it had been for several years, and the spectrum was greatly modified. In the blue-violet, forbidden lines of ionized iron in emission dominated the spectrum. Bright hydrogen lines and the pair of

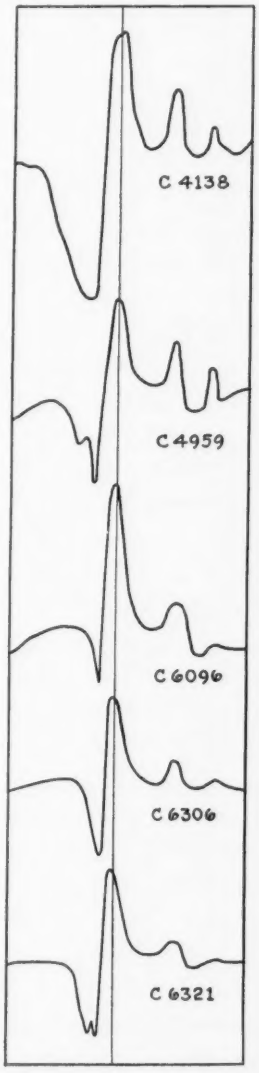


FIG. 1.—Profile of $H\gamma$ sketched from photometric tracings. Position of normal wavelength is indicated by the vertical line. The first maximum to the right corresponds to *Fe* II λ 4351.77; the second, to the position of the forbidden *Fe* II λ 4358.38, and on plate C 4959, at least, is actually due to this line.

forbidden lines of ionized sulphur near λ 4070 were present in moderate intensity, while the nebular lines, the H and K lines of ionized calcium, and the laboratory lines of ionized iron were weak. The continuous spectrum, very faint except from $H\beta$ toward the green, showed the usual M-type features of the red variable. During August and September, 1934, the Me spectrum became somewhat stronger with respect to the forbidden lines. By October 25, however, the subnormal maximum of the red variable had passed and the Me spectrum was slightly weaker relatively to the forbidden lines, which seem to have retained nearly the same intensities since July. On November 21 the Me spectrum was still less intense (although only slightly so) and the appearance of the bright line λ 4571[15] marked the phase as well past maximum. Plate C 6578, October 25, 1934, described in Table VI, is typical of this period.

A curious feature of the companion spectrum during the years since 1926 is the variation in the appearance of the hydrogen lines. On most of the plates, absorption of the P Cygni type is present on the violet edges of the emission lines, but it has constantly varied in intensity and structure. Tracings of $H\gamma$ on five plates are shown in Figure 1.

NOTES ON THE STRUCTURE OF $H\gamma$

C 4125. Resembles C 4138 (see Fig. 1)
4155. Absorption weaker and narrower than on C 4138
5551, 5854. Resemble C 4959
5641. Resembles C 6096

The absorption component is weak or absent on the following plates: C 5264, 5356, 5376, 5829, γ 18954, C 6154.

The structure of *He* λ 4471 resembles that of $H\gamma$, although the intensity is much less.

Narrow emission lines were measured in the position of the H and K lines of *Ca* II on plates V 522, C 6578, and C 6586, taken in 1934. On plate C 6306 taken in 1933, the K line seems to have both bright and dark components, but the spectrum is underexposed and the interpretation uncertain.

A condensed résumé of the general behavior of the companion spectrum and of the nebular lines is given in Table VIII.

[15] This line may be a blend of *Mg* I 4571.11 (Me) and *Ti* II 4571.98.

The companion spectrum has exhibited three principal aspects which may be briefly characterized as follows: "Ofp" type having lines of *N* III and *He* II; Bep type, strong continuous spectrum with lines of *Fe* II; 1934 type, lines of [*Fe* II] and [*S* II], continuous spectrum extremely weak.

TABLE VIII

SUMMARY OF BEHAVIOR OF COMPANION SPECTRUM

Time	Companion Spectrum	Nebular Lines
1919–1921	Not seen	Outstanding
1922–1925	Type Ofp; decreasing intensity	Outstanding
1926 July and Sept.	Weak	Moderate intensity
1926 Dec. } 1927 Jan.	Strong; type Bep; *Fe* II predominant	Weak
1927	Weak; type Ofp	Moderate intensity
1928–1933	Strong; same type as Dec. 1926	Very weak
1934	Continuous weak; [*Fe* II] predominant	Extremely weak

Measured displacements of hydrogen and iron lines in these three types are summarized in Table IX. In 1934 the hydrogen lines and the permitted lines of iron appear somewhat farther toward the red than at other times. On certain plates not included in Table IX the

TABLE IX

VELOCITIES FROM DISPLACEMENTS OF COMPANION LINES

	Hβ	*Hγ*	*Hδ*	*Fe* II	[*Fe* II]
Ofp	−29.6	−26.2	−26.5	−39.6	−28.7
Bep	31.0	34.1	31.9	32.8	39.4
1934	−21.5	−23.0	−26.9	−20.4	−35.6

displacements of the hydrogen lines in the companion spectrum differ quite definitely from the tabulated values. In most instances a peculiarity of structure is evidently responsible, but in others the cause is obscure (see Table X).

DISCUSSION

The spectroscopic data make possible a partial analysis of the light-curve of R Aquarii into two curves, one for the Me star and

the other for the companion (see Fig. 2). The procedure has a hypothetical basis: that is to say, it assumes the existence of two light-sources. It does not, however, postulate the exact character of the source of the companion spectrum. This source may be a separate companion star, itself variable in light, or possibly small areas of high temperature within the outer limits of the tenuous red variable.

The component light-curves make no claim to accuracy, but they should serve to indicate the general course of the magnitude fluctuations of the two objects. It is obvious that the light-range of the Me variable is greater and the periodicity better maintained than one

TABLE X

ANOMALOUS DISPLACEMENTS OF HYDROGEN LINES IN THE COMPANION SPECTRUM

Plate	$H\beta$	$H\gamma$	$H\delta$	Remarks
C 4472*	+16	+13	+16	Resembles 1934 type
4590	−13	−10	0	Resembles 1934 type
4125*	.....	−53	−55	Peculiar structure; overexposed at $H\beta$
4155*	+11	−14	− 6	Peculiar structure
5547	0	− 7	−26	Peculiar structure
6306	+16	(−30)†	(−38)†	Peculiar structure
6321	+ 7	−17	(−35)†	Peculiar structure

* Ten-inch camera.

† Probably blended with bright lines of the Me spectrum.

would find from the compound curve if no allowance were made for the contributions by the companion. Abnormally bright minima, as well as certain secondary maxima such as those near J.D. 2424860 and 2426250, are ascribed to the effect of the companion.

Since 1928 the maxima of the Me variable have been low, and one is tempted to connect this fact with the abnormal brightness of the companion. In 1934, however, one of the lowest of the Me maxima occurred when the companion also was very faint. Inasmuch as successions of low maxima occasionally occur in other long-period variables, judgment should perhaps be reserved on the important question of the influence of the companion on the Me variable of R Aquarii.

The brightness of the companion seems to have varied in an irregular manner. Although much of the time at the eleventh magni-

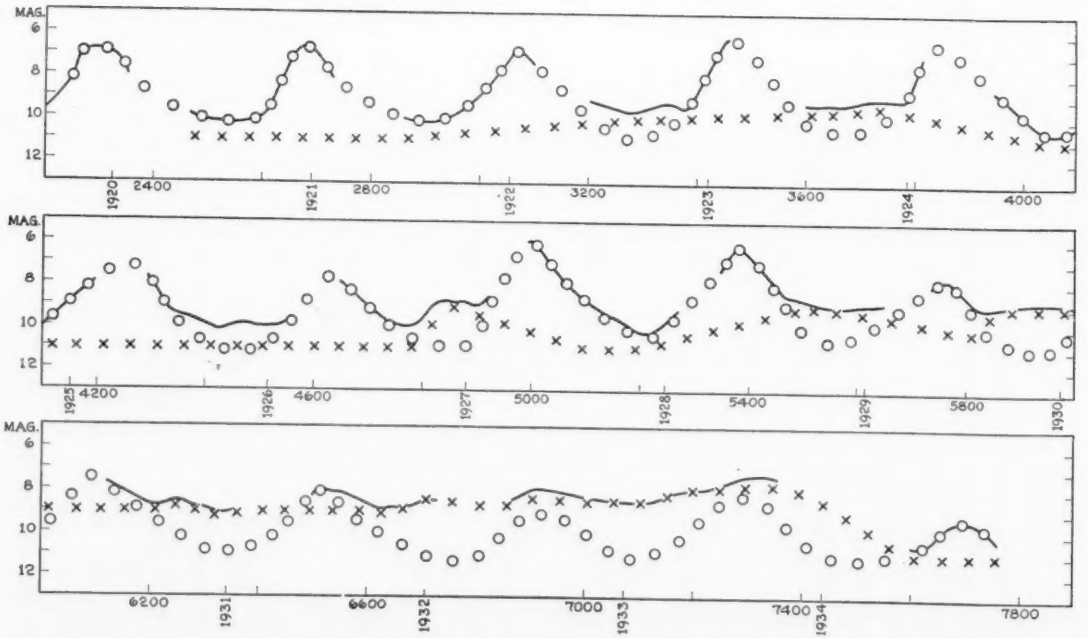


FIG. 2.—Analyzed light-curve of R Aquarii. Solid line, observed light-curve. Circles, probable light-curve of Me variable. Crosses, probable light-curve of hypothetical companion star. The Julian Day numbers are to be added to 2420000. The beginning of each calendar year is indicated.

tude or fainter, it has, on at least one occasion, been as bright as the eighth magnitude (see Fig. 2). A slight brightening in 1922 and 1923 did not extend through the years immediately following. Toward the end of 1926 a rapid and well-marked increase in brightness occurred, but the next year the companion was again faint. From 1928 to 1933 the light-curve pursued a general upward course, but in 1934 the magnitude was once more very faint.

Since the continuous spectrum of the companion is strong in the blue and violet, the color index of the combined light of the Me star and companion should decrease when the companion becomes relatively bright. This fact may allow certain deductions concerning the history of the companion to be drawn from a comparison of the visual and photographic light-curves.

TABLE XI

COMPARISON OF DISPLACEMENTS FROM VARIOUS SOURCES

Predominant	*Hβ*, γ, δ	N1, 2	λ 4363	λ 4202 λ 4308 λ 4571	*Fe* II	[*Fe* II]	Abs.
Me	−30.2	− 6.2	−26.6	−29.1	.....	.....	−14.5
Nebula	19.1	7.9	27.0	.....	.....	.....	.....
Ofp	27.4	−15.3	−29.7	.....	−39.6	−28.7	.....
Bep	32.3	.....	.....	.....	32.8	39.4	.....
1934	−23.8	.....	.....	.....	−20.4	−35.6	.....

Measured displacements of numerous lines have been recorded in Tables II, III, IV, IX, and X. The data are so complex that it is not easy to make general statements about velocities representative of the different sources. Mean displacements of several groups of lines at times when the various types of spectra were predominant are found in Table XI. Lines which appear to be blends of components from two sources have been omitted from this compilation. The bright lines in the spectrum of the companion, when not disturbed by special causes, seem by and large to have approximately the same displacements as the bright lines in the Me spectrum. This statement applies to lines of *H*, *He* I, *Fe* II, and [*Fe* II] in the spectrum of the companion and to *H*, *Fe* I (λλ 4202, 4308), and *Mg* I (λ 4571) in the Me spectrum, and is especially interesting because all these lines

have a common displacement of about 15 km/sec., or 0.2 A, toward the violet relatively to the dark lines of the Me spectrum. This fact suggests a close connection between the bright lines of the companion and those of the Me star, but in view of other circumstances a definite conclusion is unwarranted. In 1934 the hydrogen lines and the permitted lines of ionized iron exhibited small displacements toward the red. Certain instances of special aberrations of the hydrogen lines are detailed in Table X.

The remarkable behavior of the lines associated with the nebular spectrum has been noted (p. 321). During 1919 and the years immediately following, these lines had positive displacements with respect to the bright lines of the companion and Me spectra, but later, as the nebular lines became less intense, this was no longer true. One might perhaps imagine that the nebular lines in general agree with the dark lines of the M-type spectrum in yielding the actual radial velocity of the object, but the great irregularities shown by the displacements of the nebular lines make this view very uncertain. The observed irregularities may possibly have been caused by the motions of jets of nebular gases thrown off in various directions with high velocities.

The following question is probably the most important one raised by the extraordinary phenomena of R Aquarii: Is this object a casual association of a normal long-period variable with a variable planetary nebula having a variable high-temperature nucleus; or does it present an extreme example of certain phases of physical behavior which occur in a less conspicuous form in the typical Me variable? In considering this problem we naturally inquire what connections can be traced between features appearing in the spectrum of R Aquarii at various times and the spectra of other objects. The principal aspects of the spectrum of R Aquarii may be designated as Me, nebular, Ofp, Bep, and the "1934 stage." The significance of the first two designations is obvious; for the others see page 327.

The Me spectrum seems in all respects to be a perfectly typical example of that of a long-period variable. As this statement applies not only to the absorption lines and bands but to the highly specialized behavior of the bright lines, it must indicate that physical conditions in R Aquarii closely parallel those in a typical Me variable.

Forbidden lines of ionized iron may frequently be present in the spectra of Me variables near minimum light. At least the lines have been photographed in the spectra of R Leonis, χ Cygni, and U Orionis;[16] and not many other variables have been suitably observed. Thus the "1934" spectral phase of R Aquarii may not be unique.

During minima of *o* Ceti, A. H. Joy has obtained spectra whose outstanding features are:

> . . . . the hydrogen lines made up of very strong emission components with absorption centers; the strong continuous spectrum whose intensity distribution resembles that of the late B-type stars; the bright bands of helium and ionized calcium; and the fairly sharp but weak bright lines (permitted) of ionized iron. No absorption lines are seen except those accompanying the hydrogen series. The hydrogen lines at times resemble those of P Cygni.[17]

This spectrum certainly has a good deal in common with that of the Bep stage of the companion of R Aquarii. The source of the anomalous Bep spectrum in *o* Ceti is a separate star $0''.9$ from the red variable. "Unquestionably," according to Joy, "the companion is also a variable star of long or irregular period." This circumstance relates it still more closely to the hypothetical companion of R Aquarii. No other long-period variable has shown a similar Bep spectrum, but only a very few have been observed adequately except near maximum light. It would be interesting to examine a number of additional variables near minimum.

The Ofp spectrum and the nebular lines have not been found in any other long-period variable having a characteristic light-curve with a considerable range. The remarks in the last paragraph concerning the inadequacy of the observational material apply to the Ofp spectrum but not to the nebular lines. Probably more than a hundred long-period variables have been observed sufficiently to reveal nebular lines having intensities comparable to those in the spectrum of R Aquarii in 1919; nevertheless in only one additional variable has any trace of nebular lines been noted. This object, RW Hydrae,[18] HD 117970, period 370 days, in whose spectrum λ 4363 has been detected, has a less advanced M-type spectrum and a small-

[16] *Mt. W. Contr.*, No. 399; *Ap. J.*, **71**, 285, 1930.

[17] *Mt. W. Contr.*, No. 311; *Ap. J.*, **63**, 281, 1926.

[18] *Mt. W. Contr.*, No. 460; *Ap. J.*, **77**, 44, 1933.

er magnitude range than the normal variable of its period. In addition to this star three irregular variables—AX Persei,[18] CI Cygni,[18] and Z Andromedae[19]—have been found in whose spectra nebular lines are associated with titanium oxide bands. All four spectra have bright lines of *H*, *He* I, *He* II, *N* III,[20] and [*O* III], and thus exhibit a curiously striking resemblance to the spectrum of R Aquarii at times when the M-type and Ofp phases are blended. One noteworthy feature in which these four spectra resemble (or surpass) that of R Aquarii is the high intensity of λ 4363 compared to that of the green pair λλ 4959, 5007. This relationship probably indicates a higher pressure than that which prevails in most gaseous nebulae.

These similarities with other objects, while not leading at once to the true interpretation of the spectroscopic phenomena of R Aquarii, do encourage the belief that certain features of rather general astrophysical interest, which may be elucidated as our knowledge of stellar spectra increases, lie back of these phenomena.

Marked changes have not been noted in the outer lenticular nebulosity discovered by Lampland.[21] Uniform intensity of the light from this structure would require a constant stimulating source which, if located in the central star, does not seem compatible with the great changes observed in the nebular lines and in the Me and companion spectra. Constant radiation in the far ultra-violet might serve the purpose, but it would be remarkable if this were coexistent with the extraordinary changes observed at longer wave-lengths. Continued observations, with photometric control, of the nebular arcs would be of the greatest interest.

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MOUNT WILSON OBSERVATORY
December 1934

[19] H. H. Plaskett, *Pub. Dom. Ap. Obs.*, **4**, 119, 1928; Frank S. Hogg, *Pub. A.S.P.*, **44**, 328, 1932.

[20] *N* III doubtful in RW Hydrae because of the presence of the strong M-type spectrum.

[21] *Op. cit.*, p. 162.

ANGULAR ROTATIONS OF SPIRAL NEBULAE*

By EDWIN HUBBLE

The outstanding discrepancy in the current conception of nebulae as extra-galactic systems lies in the large angular rotations announced more than a decade ago by Dr. van Maanen.[1] The extraordinary significance of the phenomena, if they are real, has led the writer to remeasure four of the principal nebulae, M 81, M 51, M 33, and M 101.

TABLE I

COMPARISON OF OBSERVED AND EXTRAPOLATED ROTATIONAL COMPONENTS

(Unit = 0.001 mm for total interval)

	Means for 2 Pairs of Plates			Single Pair with Longest Interval		
	Interval	Obs.	Extrapolated	Interval	Obs.	Extrapolated
M 81*.....	15 yrs.	−2.0	+16	22 yrs.	−2.5	+23
51*.....	23	+1.5	16	23	+1.5	16
33.....	22	0.0	17	23	−0.1	18
101.....	16.5	+0.6	+13	23	0.0	+19
Mean...	19.1	0.0	+15.5	22.8	−0.3	+19.0

* The results for M 81 and M 51 include measures by Nicholson and by Baade. Two recent plates of M 33 were measured against a single early plate.

In general, two early[2] and two late plates of each nebula, all made with the 60-inch reflector (Newtonian focus), were measured independently on a double-slide measuring machine, using about 20 reference stars and 50 nebular points. The results are given in Table I, in the form of total rotational displacements of the nebular points with respect to the reference frames, expressed in units of 0.001 mm

* *Contributions from the Mount Wilson Observatory, Carnegie Institution of Washington*, No. 514.

[1] *Mt. W. Contr.*, No. 260; *Ap. J.*, **57**, 264, 1923, where van Maanen gives a critical review of his results and includes references to his earlier papers. See also the *Mt. W. Annual Report*, 1930–1931.

[2] Only one early plate suitable for measuring was available for M 33. Most of the early plates were the same as those used by van Maanen.

$=0''.027$. The results in all cases are comparable with the uncertainties of the measures, estimated as of the order of 0.002 mm, and various known proper-motion stars, included as checks, afford some direct evidence against the existence of serious systematic errors.

At the writer's request, Dr. Nicholson measured one of the pairs for M 81 and Dr. Baade the two pairs for M 51. The displacements in each case agree with the writer's results within the uncertainties of measurement and do not indicate rotations of the order expected.

Two sets of measures are thus presented, each internally consistent, differing by the large systematic terms which van Maanen has interpreted as rotations. Since several of the same plates were used, systematic errors of measuring are obviously present in one of the two sets. A careful study of the longest intervals with the blink comparator gives no indication of systematic displacements although the values of the extrapolated rotations should be above the threshold of perception. These results establish the existence of some systematic errors in the rotations although they indicate only lower limits to the actual amounts of the errors.

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MOUNT WILSON OBSERVATORY
February 1935

INTERNAL MOTIONS IN SPIRAL NEBULAE *

By ADRIAAN VAN MAANEN

In my measures of the internal motions in spiral nebulae, practically all of which were based upon long-exposure photographs taken at the 25-foot focus of the 60-inch reflector, I have always borne in mind the fact that there were several sources of possible systematic error in the material. Among these were the length of the exposures, which in some cases extended over several nights; the very large hour angles involved; the choice of comparison stars, which in general were brighter than the nebular points and at considerable distances from the center of the plates; and possible systematic effects due to differential coma. After the publication of my results for M 33 in 1923 it was accordingly considered desirable to postpone further investigations until photographs taken with the 100-inch telescope became available.

For two nebulae, M 33 and M 74, pairs of such plates with an interval of nine years have now been measured. In both cases the exposure times were about one hour and care was taken that the hour angles should be practically the same for the plates compared. The measures give motions for both nebulae in the same direction as those found for the spirals measured previously; but the value for M 33, mean of 114 nebular points, is considerably smaller (+0″.013 as compared with +0″.020) than that found before, and that for M 74, mean of 76 nebular points, which had not been measured previously, is only +0″.008. A few plates of M 33 and M 101 taken at the 80-foot focus of the 60-inch telescope also show the same direction of motion as before, but here, too, the amount is smaller, +0.009 and +0.013, respectively. Only 9 and 6 points, respectively, could be measured on these 80-foot-focus plates.

In consideration of the difficulty of avoiding systematic errors in this special problem, these results, together with the measures of

* *Contributions from the Mount Wilson Observatory, Carnegie Institution of Washington*, No. 515.

Hubble, Baade, and Nicholson which are given in the preceding article, make it desirable to view the motions with reserve. Although my own measures of recent plates made in a purely differential way with the stereocomparator show considerably smaller values of the apparent rotational component than those first obtained, the persistence of the positive sign is very marked and will require the most searching investigation in the future. For this purpose photographs are being taken with the 100-inch telescope under conditions which may avoid some of the possible systematic influences mentioned at the beginning of this note.

CARNEGIE INSTITUTION OF WASHINGTON
MOUNT WILSON OBSERVATORY
February 1935

CHROMOSPHERIC EMISSION IN THE WINGS OF H AND K*

By A. D. THACKERAY[1]

ABSTRACT

Certain lines near the centers of the H and K Fraunhofer lines appearing in *emission* near the solar limb *extend abnormally far into the disk*, as noted by Evershed, in some cases reappearing in absorption at the center. The phenomenon is explained as a lack of radiation to be absorbed, the atoms being able to reach the upper state prior to emission by absorption of other wave-lengths outside H and K. Two lines are identified as due to Nd^+ and Ce^+, indicating that these atoms emit and absorb mainly *above* the layers in which Ca^+ absorption takes place.

Some years ago Evershed[2] drew attention to certain reversals appearing in the solar limb spectrum within the wings of H and K. The strongest of these at λ 3934.80 was originally discovered by Jewell[3] in 1898. The behavior of these lines recalls Menzel's[4] "c"-characteristic of flash lines (i.e., emission extending well into the disk), which is shown most markedly by the ionized rare earths, and Menzel in fact gives a chromospheric line at λ 3934.89 which he identifies as due to Nd^+. The writer is indebted to A. S. King for a revised laboratory wave-length of 3934.813 for the Nd^+ line, so that we may identify this with some confidence with Jewell's line. The accompanying table summarizes the data relating to the four lines observed by Evershed. Measurements of the first two lines (limb emission) from Mount Wilson plates give 3931.546 and 3934.805, confirming Evershed's wave-lengths.

The identification of λ 3931.54 with Ce^+ must be regarded as very doubtful, owing to the discrepancy in wave-length; that of λ 3969.40 with Eu^+ is less so, as the reversal appears on the red side of a strong *Fe* line (intensity 10) and Mount Wilson plates suggest there may be reversal on the violet side too. The identification of the other two lines is more certain.

* *Contributions from Mount Wilson Observatory, Carnegie Institution of Washington*, No. 516.

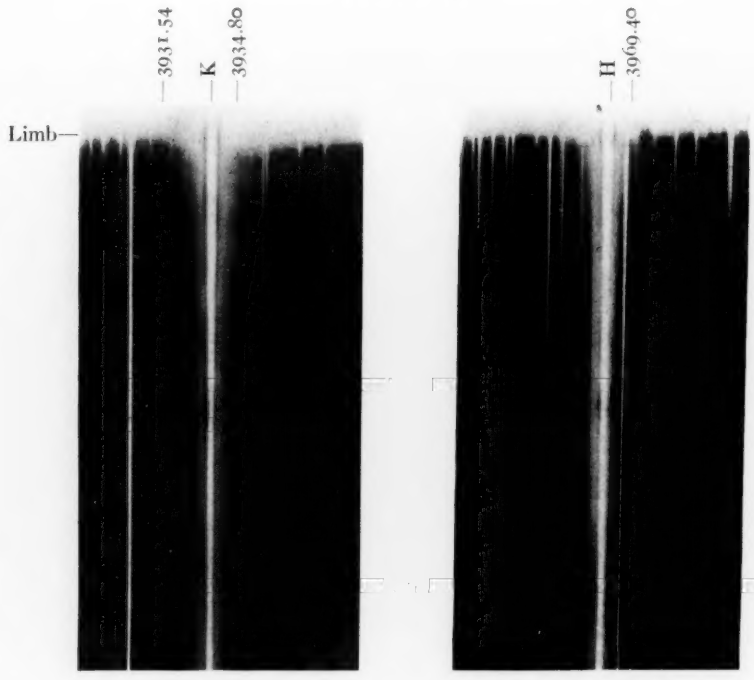
[1] Fellow in astronomy on the Commonwealth Fund.

[2] *M.N.*, **87**, 350, 1927, and **89**, 566, 1929.

[3] *Ap. J.*, **8**, 119, 1898.

[4] *Pub. Lick Obs.*, **17**, 8, 1931.

PLATE IV



SPECTRA OF H AND K NEAR LIMB (NEGATIVES)
Slit radial to limb; vertical scale, solar diameter = 95 cm

UNIV. OF MICH.

Although examination of other rare-earth lines in limb spectra taken in good seeing show some signs of reversal or weakened absorption, it is clear that the four lines considered here show strong reversal which extends unusually far (even for rare-earth lines) into the disk.[5] The reason is not difficult to see when we consider the effect of the H and K wings. Absorption depends on the intensity of the incident radiation of the particular line frequency and this is abnormally low within the wings of H and K (at λ 3934.80 photometric measures show that the intensity is reduced to 0.20 of the continuous spectrum); emission, however, depends on the number of

Emission at Limb (Evershed)		Absorption (Center) (Revised Rowland)		Chromosphere (Menzel)		Identification	
λ	Int.	λ	Int.	λ	Element	λ	Element
3931.54.....	0	? 3931.59	1	{3931.28	*V*? *Ce*?	? 3931.371	Ce^+
				31.74	?		
34.80.....	2	.....	.....	34.89	Nd^+	34.813	Nd^+
67.04.....	0	3967.057	od?	.....	.....	67.048	Ce^+
3969.40.....	3	.....	.....	3969.27	*Fe*, Eu^+ (c to red)	? 3969.23	Eu^+

atoms in the upper state and on constant transition probabilities. Atoms can reach the upper state by absorption of frequencies outside H and K and thus the lines considered here are more readily emitted than absorbed. The fact that the reversals appear only at the limb is explained because the contribution of emission (in random directions) is here more important than that of absorption, which is mainly of radiation passing radially outward, and also because we look tangentially along a longer path in the upper layers where the effect will be most marked.

The phenomenon should affect to some extent all lines within the wings of another and much stronger line. The fact that it appears only for rare-earth lines seems to indicate that these atoms can only emit and absorb in layers above those in which most of the H and K absorption takes place. For other lines the absorption in the

[5] λ 3934.80 can be traced to about a minute of arc from the solar limb.

lower layers must be too great to be overbalanced by the fluorescence in the upper layers. It is noteworthy in this respect that Evershed's two weakest emission lines appear as weak absorption lines in the solar disk spectrum, whereas the stronger pair have not been observed in absorption; for the latter, presumably, absorption is just balanced by fluorescence. It is probable that all lines within the H and K wings show more weakening at the limb than those outside and it is hoped to test this in future. Excellent seeing is required for this work as plates taken under poor conditions have entirely failed to show the reversals.

The reversals do not appear in sun-spot spectra and so far have not shown signs of strengthening over faculae.

Mention should also be made of the unidentified line λ 3938.300 to which Menzel has already called attention. This line appears in absorption with intensity 2, but weakens rapidly near the limb, finally disappearing altogether.

CARNEGIE INSTITUTION OF WASHINGTON
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ON THE SPECTRUM OF γ CASSIOPEIAE

By J. F. HEARD[1]

ABSTRACT

Spectrograms of the bright-line star γ Cassiopeiae taken recently with prism and grating instruments have been examined and compared with spectrograms of the same star taken previously with the same instruments.

A new list of wave-lengths and identifications of emission lines is given for the visual region.

Some unusual changes in the emission spectrum during 1934 are described.

The spectrum of the star γ Cassiopeiae, spectral class Boe, has been studied extensively by a number of observers, including Curtiss[2] and Miss Heger,[3] who have published accounts of the visual region; Struve and Swings,[4] who have published an account of the photographic region; and McLaughlin[5] and Lockyer,[6] who have described slight changes in the spectrum. The present communication adds to the description of the visual region and describes some radical changes which have taken place in the spectrum during 1934.

For an examination of the visual region of the spectrum ($H\beta$–$H\alpha$), a number of plates taken by Messrs F. E. Roach and J. A. Hynek in 1932, 1933, and 1934 with the Yerkes grating spectrograph attached to the 69-inch reflector of the Perkins Observatory were available. The emission lines on the best of these plates were measured. All emission lines were broad and double. Table I lists the wave-lengths, estimated intensities, and identifications of the lines.

The sodium D lines are present in absorption; they are very narrow and appear to be of interstellar origin.

Table I lacks a few of the lines reported by Miss Heger[7] and adds a few lines not reported by her. The presence of *Sc* II and *Cr* II, which was considered uncertain by Struve and Swings,[8] is confirmed.

An examination of the photographic region of the spectrum was made from a long series of plates taken with the Bruce one-prism

[1] 1851 Exhibition Student.

[2] *Pub. Michigan Obs.*, **2**, 1, 1916.

[3] *Lick Obs. Bull.*, **10**, 149, 1922.

[4] *Ap. J.*, **75**, 161, 1932.

[5] *Pub. Michigan Obs.*, **4**, 177, 1932.

[6] *M.N.*, **93**, 362, 1933; **93**, 619, 1933.

[7] *Loc. cit.*

[8] *Loc. cit.*

spectrograph and from a few plates taken recently with the prism spectrograph at the Perkins Observatory. The emission lines measured on a number of these plates agree well with those measured by Struve and Swings. Several plates, however, taken in 1934 show *He* I 4471 in emission as well as in absorption; this line is definitely not present in emission on plates taken previous to 1934. Again, on the Perkins prism plates (which extend well into the ultra-violet) the

TABLE I

EMISSION LINES OF γ CASSIOPEIAE

Wave-Length	Int.	No. of Plates	Identification	Wave-Length	Int.	No. of Plates	Identification
4861.3.....	50	6	*Hβ*, 4861.3	5875.6.....	10	6	*He* I, 5875.6
4924.3.....	7	4	*Fe* II, 4923.9	6148.9.....	2	3	*Fe* II 6147.9, 6149.3
5018.5.....	5	6	*Fe* II, 5018.5	6158.9.....	1	1	*Cr* II, 6158.8
5168.9.....	5	6	*Fe* II, 5169.1	6238.6.....	1	1	*Fe* II 6238.4, 6240.0
5181.9?....	1	1	.....	6248.4.....	2	2	*Fe* II, 6247.6
5197.8.....	4	6	*Fe* II, 5197.6	6318.3.....	5	4	.....
5224.2.....	2	2	.....	6347.3.....	2	4	*Si* II, 6347.1
5234.8.....	3	6	*Fe* II, 5234.6	6371.0.....	1	2	*Si* II, 6371.4
5254.3.....	1	2	*Fe* II, 5256.9	6384.2.....	3	4	*Fe* II, 6383.7
5264.7.....	2	3	*Fe* II, 5264.8	6400.1?....	2	1	.....
5275.8.....	3	6	*Fe* II, 5276.0	6417.4.....	1	1	*Fe* II, 6417.4
5284.2.....	2	5	*Fe* II, 5284.1	6432.7.....	2	2	*Fe* II, 6432.7
5316.4.....	5	6	*Fe* II 5316.6, 5316.8	6443.9.....	2	3	.....
5326.2.....	1	2	*Fe* II, 5325.8	6455.9.....	3	4	*Fe* II, 6456.4
5362.5.....	2	5	*Fe* II, 5362.9	6516.2.....	1	1	*Fe* II, 6516.1
5424.7.....	1	2	*Fe* II, 5425.3	6562.7.....	50	4	*Hα*, 6562.8
5526.2.....	1	1	*Sc* II, 5526.8				
5534.5.....	3	5	*Fe* II, 5534.8				

presence of *He* I 3888.6 is indicated by an enhancement of *Hζ* (3889.1) with respect to the other members of the Balmer series. No earlier Perkins plates are available to determine whether this *He* I line is also new in 1934, but no previous investigators have reported it.

In the matter of the appearance of emission lines of both *He* I and *Fe* II, the star γ Cassiopeiae is peculiar. A number of Be stars show *He* I in emission and a number show *Fe* II in emission, but in very few stars do both appear together. Moreover, the enhancement, as here observed, of the *He* I emission lines without a weakening of the

Fe II emission lines precludes any simple explanation on the basis of excitation potentials.

Among the identified emission lines of γ Cassiopeiae no intensity anomalies have been observed. The *Fe* II spectrum is complete even to the solar lines which do not appear in the laboratory spectrum; these solar lines are weakest and the other *Fe* II lines agree well in intensity with the laboratory lines. Of the other atoms which yield emission lines—*He* I, *Si* II, *Sc* II, *Cr* II, etc.—only the strongest laboratory lines appear. The Balmer series has been traced in emission as far as H_{20}. Several strong lines, notably λ 6318.3 and λ 6443.9, have not been identified.

VARIATIONS IN THE SPECTRUM

The question of the constancy of the spectrum of γ Cassiopeiae has been the subject of much discussion among observers of this star. Curtiss,[9] in 1916, could observe no variations from the Michigan plates then at hand. McLaughlin,[10] however, from an examination of Michigan plates from 1911 to 1930, suspected some slight changes in the emission ratio of the violet to the red components of *Hγ*. Lockyer,[11] examining a very complete series of plates taken at Sidmouth, has observed variations in the emission ratios of *Hγ*, *Hδ*, *Hε*, and *Hζ*, and he has concluded that these variations have roughly a four-year period. Yerkes one-prism spectrograms extend from 1902 to the present time, but the series is not sufficiently complete to test Lockyer's period; eye estimates, by the writer, of the emission ratios of the hydrogen lines show that at times the red components are stronger, while at other times the violet components are stronger, but the estimates do not fit well into Lockyer's curves. However, it is certain, in agreement with Lockyer's observations, that the intensities of the violet and red components during 1933 were very much more unequal (the violet components being the stronger) than at any previous time for which observations are available. The spectrograms taken during September, October, and November of 1934 show an even greater inequality in the intensities of the components of the hydrogen lines, the red components being now very intense and the violet components so weak as to be almost

[9] *Loc. cit.* [10] *Loc. cit.* [11] *Loc. cit.*

lost. These intensity variations are shared by the other bright lines of the spectrum, but not to the same extent; in particular, the 1934 spectrograms do not show as great an intensity ratio (R/V) for the *Fe* II, *He* I, etc., lines as for the hydrogen lines.

A still more striking feature of the 1934 spectrograms is a decrease of about 35 per cent in the separations of the two components of all

TABLE II

SEPARATIONS OF EMISSION DOUBLETS

Plate	Doublet Separation (Km/Sec.)	Lines Measured
Bruce three-prism, Oct. 27, 1928	166	$H\beta$
Bruce one-prism, Feb. 25, 1931	167	$H\gamma$, $H\delta$, $H\epsilon$; *Fe* II 4233.2
Bruce one-prism, June 29, 1933	167	$H\beta$, $H\gamma$
Grating, Oct. 31, 1933	162	*Fe* II 5169.0, 5316.6
Grating, Sept. 21, 1934	113	*Fe* II 5169.0, 5316.6
Bruce one-prism, Nov. 14, 1934	125	$H\gamma$, $H\delta$, $H\epsilon$; *Fe* II 4233.2

emission lines. No such change has been reported before, and a search for variations of this kind on plates available here has revealed none prior to 1934.

The separations of the components of the best lines on a number of plates have been measured and the measures reduced to kilometers per second and averaged for each plate. The results are shown in Table II.

The writer wishes to express his thanks to Professor Otto Struve for suggesting this problem and for much helpful advice.

YERKES OBSERVATORY
November 1934

THE VELOCITY-CURVE OF 27 CANIS MAJORIS

By OTTO STRUVE

ABSTRACT

The long-period velocity-curve of this spectrum variable does not exactly repeat itself in successive minima and cannot be attributed to orbital motion. Superposed over this curve is a variation having a period of approximately 118 days and a range of 50 km/sec. The total observed range in velocity is about 250 km/sec.

Two years ago J. L. Halpern[1] announced that the radial velocity of 27 Canis Majoris had started toward a minimum and was then in

TABLE I

RADIAL VELOCITIES OF 27 CANIS MAJORIS

Date G.C.T.	Observers	Quality	Velocity Km/Sec.
1933 Oct. 17.46	σ, S	g	−35
1933 Oct. 18.45	P, S	g	−28
1933 Oct. 31.44	M, S	g	−30
1933 Nov. 28.42	σ, S	g	−26
1933 Dec. 6.39	Hy, S	p	+13
1934 Jan. 26.20	σ, S	f	−30
1934 Feb. 15.17	σ, S	g	−43
1934 Feb. 19.17	σ, S	g	−41
1934 Feb. 27.13	P, S	g	−35
1934 Mar. 10.08	Hy, S	G	−23
1934 Apr. 1.07	M, S	f	−45
1934 Oct. 7.45	M, Mc, S	g	−42
1934 Oct. 10.46	σ, S	g	−70
1934 Oct. 12.44	M, Mc, S	g	−45
1934 Oct. 13.43	H, S	g	−50
1934 Oct. 16.46	σ, Hd, S	f	−31
1934 Oct. 22.48	σ, Hd, S	g	−35
1934 Oct. 26.41	M, S	f	−31
1934 Oct. 30.45	M, S	g	−36
1934 Nov. 7.48	H, S	g	−32
1934 Nov. 24.31	Mc, H, S	f	−12
1934 Dec. 31.28	Mc, H, S	p	−17
1935 Jan. 4.26	Mc, S	g	−13

Hd = J. Heard; H = L. Henyey; Hy = J. Hynek; M = W. Morgan; Mc = E. McCarthy; P = H. Pillans; σ = O. Struve; S = F. R. Sullivan; g = good; f = fair; p = poor.

approximately the same stage as in the spring of 1926. A period of approximately 2500 days was suggested by the observations.

[1] *Ap. J.*, **78**, 64, 1933. For earlier observations see *ibid.*, **65**, 273, 1927; **66**, 113, 1927; **68**, 109, 1928; **73**, 301, 1931; **75**, 158, 1932.

Table I gives a list of new observations, and Figure 1 is a graphical representation of all radial velocities obtained at the Yerkes Observatory since 1925.

The descending slope of the curve for 1933–1934 is distinctly less steep than that for 1926–1927. The minimum velocity, which in 1928 almost touched −120 km/sec., never went below −70 km/sec. in 1934. It is therefore safe to state that this velocity-curve does not represent orbital motion, and that consequently 27 Canis Majoris should be dropped from the list of binaries.

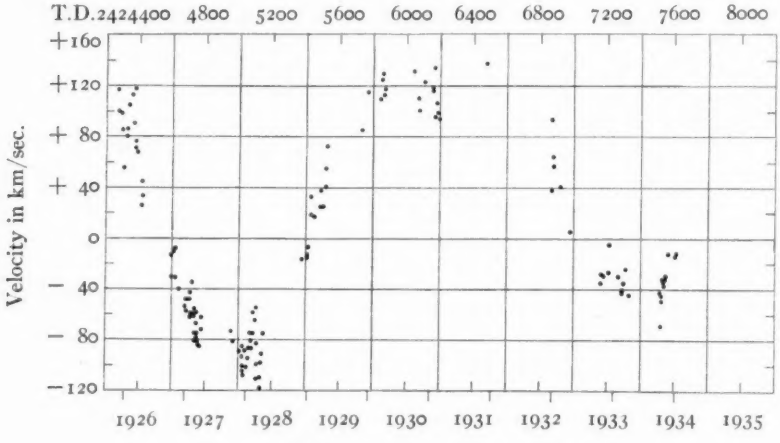


FIG. 1.—Velocity curve of 27 Canis Majoris

This result leaves our knowledge of double stars in a decidedly improved state; not only does it remove from consideration an improbably large mass, but it also removes one of the outstanding contradictions to the mass-luminosity relation.[2]

On the other hand, there is no explanation for the large range in velocity. The measurements are based principally upon several lines of *H* and of *He* I, respectively, and the results from individual lines are fairly concordant, although in a few cases systematic differences have been suspected between the results from different lines.

The intensities of the absorption lines vary, as was described in a former paper.[3] During the deep maximum of 1927–1928 the stronger

[2] The interstellar lines are faint and the luminosity cannot be very great.

[3] *Ap. J.*, **73**, 301, 1931.

absorption lines were deep and the gradient was large. During the present minimum the lines have retained the appearance characteristic for the phase of maximum velocity; most of them are weak and ill defined.

No emission lines were clearly seen on any of the plates obtained since 1933. But the lines of *He* I and of *H* often displayed the same type of structure that in earlier papers was interpreted as evidence of a fainter binary component. No attempt is made here to measure these components.

TABLE II

List of Maxima Observed	Computed (P=117^{d}8)	O−C
J.D. 2424450	4462	−12
4580	4580	Assumed
4820	4816	+ 4
4920	4933	−13
5160	5169	− 9
5300	5287	+13
5630	5640	−10
5720	5758	−38
6240	6229	+11
6360	6347	+13
7410	7407	+ 3
7760	7761	− 1

The radial velocities, which in all cases refer to the strongest spectral component, show a fairly definite variation having an amplitude of about 50 km/sec. Table II gives a list of the observed maxima; these are best satisfied by a period of 117.8 days. Unfortunately, the average velocity-curve is not known with sufficient precision to permit the isolation of the short-period variation.

The best hypothesis for the explanation of the phenomena in 27 Canis Majoris is probably that proposed by McLaughlin[4] for Be stars. Notwithstanding the faintness of the emission lines and the large range in velocity, McLaughlin's suggestion[5] that 27 Canis Majoris may be related to other Be stars is supported by the present investigation.

YERKES OBSERVATORY
January 9, 1935

[4] *Proc. Nat. Acad.*, **19**, 44, 1933.

[5] *Ap. J.*, **75**, 60, 1932.

A PECULIAR SPECTROSCOPIC PHENOMENON IN THE ALGOL SYSTEM

By W. W. MORGAN

ABSTRACT

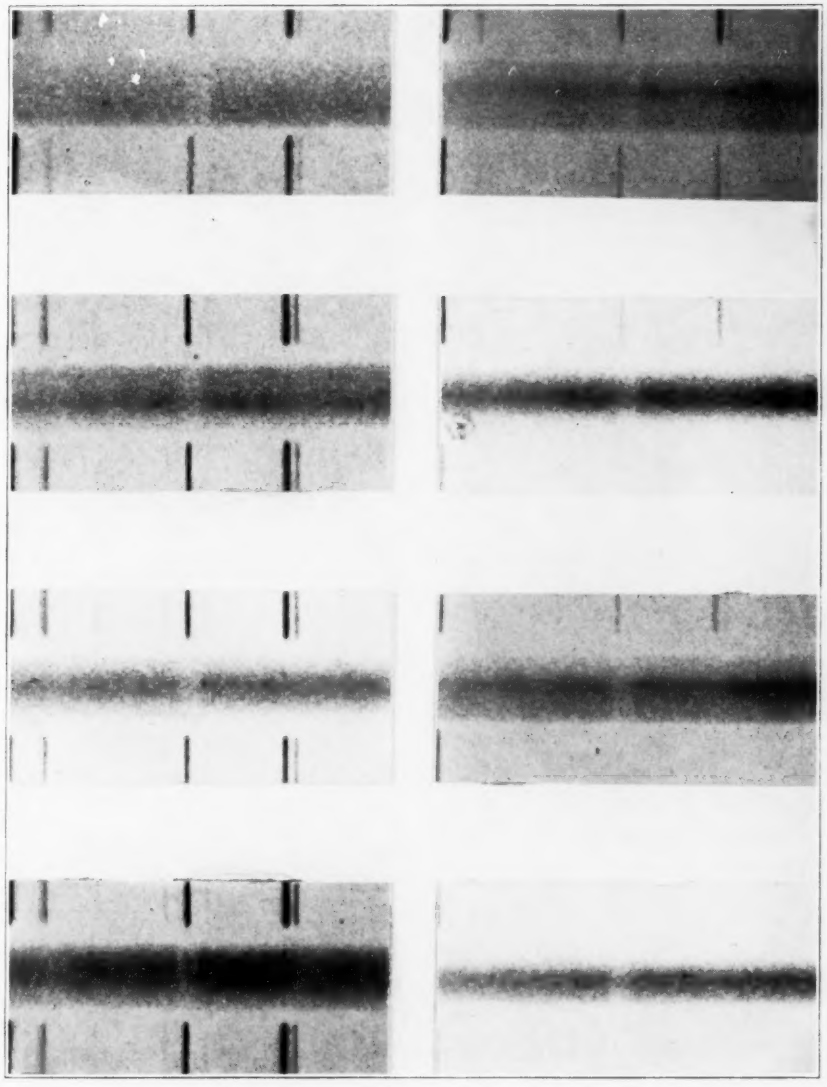
The line *Mg* II 4481 in the spectrum of Algol is double at and in the vicinity of primary light minimum. The relative velocity of the two components, which is probably constant over the observed time, is about 60 km/sec. The individual velocities of the two components are constant after orbital motion has been eliminated. In addition to λ 4481, *Fe* II 4549 is also almost certainly double. These are the two strongest lines in the observed range, with the exception of the broad hydrogen lines. It is probable that the doubling is apparent only and that it is due in some way to the effect of the secondary component on the contours of the lines of the primary.

Several series of three-prism spectrograms were obtained in 1930 at the Yerkes Observatory in connection with an investigation of stellar rotation which was being made by Struve and Elvey.[1] The scale of the plates is 10 A per millimeter at λ 4500 and the exposure times range from twenty to forty minutes. A plate with its exposure centered at phase 0.019 days after principal light minimum was at the time suspected by Struve of showing a double *Mg* II 4481, but it was considered that other plates did not confirm the apparent duplicity. A more extended examination of all of the material now leaves no doubt that the line is actually double between phases $-0^d.04$ and $+0^d.04$. All plates of good quality which were taken between these phase limits give evidence of duplicity and on several of them the doubling is quite pronounced. The region around λ 4481 is shown on Plate V, for all usable spectrograms obtained between phases $-0^d.044$ and $+0^d.033$. The red component is stronger before mid-eclipse and the violet component afterward. In addition to *Mg* II 4481, *Fe* II 4549 seems definitely double on several plates. The line, although considerably weaker than λ 4481, is stronger than any other line in the observed spectral range, with the exception of the broad *Hβ* and *Hγ*.

The radial velocities of the two components of λ 4481 were measured on seven of the eight spectrograms shown in Plate V. When

[1] *M.N.*, **91**, 663, 1931.

PLATE V



SPECTRA OF ALGOL SHOWING APPARENT DOUBLING OF *Mg* II 4481

The phases are reckoned from primary minimum

(The reproduction should be held at arm's length for examination)

UNIV. OF MICH.

the resultant velocities were corrected for both long-period and short-period orbital motion from the elements derived by McLaughlin,[2] they were found to be sensibly constant throughout the time limits included. The radial velocity data are given in Table I.

The columns give: (1) the date; (2) the phase from light minimum; (3)–(6) the radial velocities and intensities of the two components uncorrected for orbital motion; (7) the velocity of the mean of the two components; (8) the radial-velocity measures by Struve[3]

TABLE I

Heliocentric Date U.T. 1930	Short-Per. Phase	I		II		$\frac{I+II}{2}$	Struve	$\frac{I+II}{2}$ Corrected for Long and Short Per.	Vel. (S) Corr. for Long and Short Per.
		Vel.	Int.	Vel.	Int.				
Dec. 25.288...	−0.044	−26.8	1–2	+47.5	3	+10.4	+38.5	−11.7	+16.4
Nov. 18.019...	− .038	11.4	1	40.1	2	14.4	+30.1	5.7	+10.0
Dec. 28.178...	− .022	13.0	1	39.9	1	14.0	+21.9	6.1	+ 1.8
Nov. 18.047...	− .010	18.1	2	36.1	2	9.0	+15.1	7.6	− 1.5
Dec. 28.206...	+ .006	17.1	1	40.4	1:	11.6	+ 6.8	5.9	−10.7
Nov. 18.076...	+ .019	24.1	3	40.8	2	8.4	− 6.6	6.6	−21.6
Dec. 28.233...	+0.033	−20.4	2–3	+35.1	1:	+ 7.4	−18.0	− 7.4	−24.8

on the assumption that the lines are single; (9) the velocity of the mean of the two components corrected for long-period and short-period orbital motion; and (10) the velocities by Struve corrected for orbital motion.

The velocity of the mean of the two components remains constant after corrections have been applied for orbital motion. From the fact that the mean values of the velocities determined from the two components agree with the velocity curve of the primary, it seems probable that the apparent doubling of the lines is due in some way to the partial superposition of the disk of the secondary over that of the primary. It is difficult to see, however, how any such superposition can cause the pronounced doubling observed. The rotation effect, which was discovered by McLaughlin, has also been investigated by Struve and Elvey. The latter computed theoretical con-

[2] *Ap. J.*, **60**, 22, 1934.

[3] *Loc. cit.*

tours from the constants of the system which show pronounced asymmetry but which do not suggest an apparent doubling of the lines.

As the red component is stronger before mid-eclipse and the violet component afterward, measures of the center of gravity of the two components would tend to show a variation similar to that actually

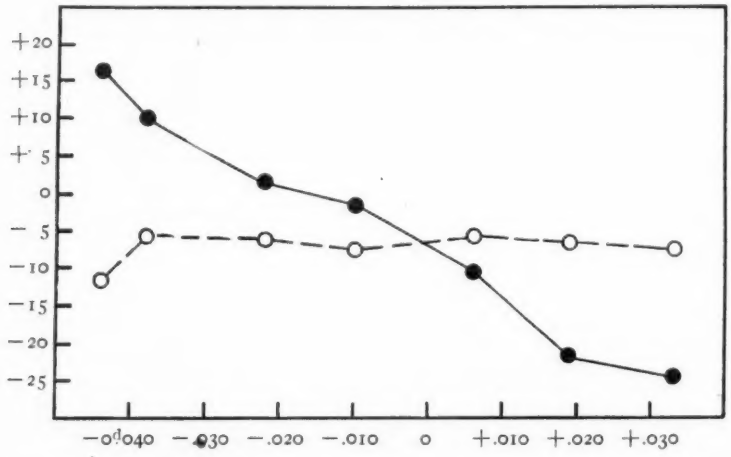


FIG. 1.—Radial velocity of Algol near primary light minimum. Solid circles are Struve's measures of the centers of gravity of the lines. Open circles are the arithmetical means of measures of the two components. Both short- and long-period velocity variations have been removed. Abscissas are phases in days from primary minimum; ordinates are velocities in km/sec.

found in the rotation effect. Figure 1 shows the behavior with phase of the mean of the positions of the two components, together with the radial velocities determined by Struve from the same plates on the assumption that the lines are single. His velocities depend principally on the two lines *He* I 4471 and *Mg* II 4481.

I am greatly indebted to the observers who secured the excellent series of spectrograms. Those participating in the observing were O. Struve, P. C. Keenan, H. F. Schwede, and F. R. Sullivan.

YERKES OBSERVATORY
WILLIAMS BAY, WIS.
November 24, 1934

NOTES

PARTIAL LIST OF c STARS OF CLASSES B AND A*

ABSTRACT

Table I lists 95 c stars of classes B and A, most of which have been either discovered or confirmed by observations with slit spectrographs at Mount Wilson. The average absolute magnitude is thought to be about -5.0. The number of stars having hydrogen emission is noteworthy.

Since Miss Maury's early work, stellar spectra that, in comparison with others of the same type, have unusually distinct lines and other features characteristic of high luminosity have been designated by the letter "c" added to the type symbol. These stars receive considerable attention not only because they have physical properties of special interest but because they are more distant than other stars of the same apparent magnitudes.

The chief sources for the identification of c stars have previously been:

1. Remarks in the Harvard catalogues of spectra. *H.A.*, **28, 50, 91–99.** Most of the stars concerned are listed in Appendix A of *The Stars of High Luminosity*, by Cecilia H. Payne.
2. The Mount Wilson determinations of spectroscopic parallax. W. S. Adams and A. H. Joy, *Mt. Wilson Contr.*, Nos. 244, 262; *Ap. J.*, **56,** 242, 1922; *ibid.*, **57,** 294, 1923.
3. The spectral classifications collected in "A Catalogue of the Radial Velocities of O and B Stars," by J. S. Plaskett and J. A. Pearce, *Pub. Dom. Ap. Obs.*, **5,** 99, 1931.

The most important criteria that distinguish c stars appear to be:

1. Distinct, narrow lines without wings.
2. Relative intensification of certain lines.

Types B0–B3	*O* II, *N* II, *Si* III, *Si* II
B5–B8	*Si* II, *He* I
A0–A5	*He* I, *Si* II, *Fe* II

Typical stars are: χ^2 Orionis, cB1eα; β Orionis, cB8; α Cygni, cA2eα. Features that may eventually become useful are the tendency

* *Contributions from the Mount Wilson Observatory, Carnegie Institution of Washington*, No. 512.

TABLE I

c STARS OF CLASSES B AND A

H.D.	Name	Spec.	Mag.	R.A. 1900	Dec. 1900	l	b
698	.....	B8ea	7.1	$0^h\ 6^m3$	$+57°39'$	85°	$-4°$
(2,885)	β^2 Tuc	A2	4.5	0 27.0	−63 31	272	−54
2,905	κ Cas	Boea	4.2	0 27.3	+62 23	89	0
4,768	.....	B3	8.0	0 44.6	+59 7	91	− 3
4,841	.....	B5	7.1	0 45.4	+63 14	90	− 1
7,902	.....	B5ea	7.9	1 13.6	+57 40	95	− 4
8,065	.....	A2	6.1	1 15.0	+78 12	92	+16
9,105	.....	B5(e)	7.5	1 24.6	+62 51	95	+ 1
12,301	53 Cas	B8	5.6	1 55.6	+63 54	98	+ 3
12,953	Boss 478	A2ea	5.9	2 1.7	+57 57	101	− 2
13,267	5 Per	B8	6.4	2 4.6	+57 11	101	− 3
13,476	.....	Ao	6.5	2 6.6	+58 6	101	− 2
13,744	.....	Ao	7.8	2 8.9	+57 50	102	− 2
13,841	.....	B2	7.2	2 9.8	+56 34	102	− 3
13,854	Boss 507	B1ea	6.4	2 9.9	+56 36	102	− 3
13,866	.....	B2	7.7	2 10.0	+56 15	102	− 4
(14,010)	.....	B8	7.0	2 11.1	+63 58	100	+ 4
14,134	Boss 519	B3ea	6.7	2 12.1	+56 40	102	− 3
14,143	.....	B1	6.7	2 12.2	+56 43	102	− 3
14,322	.....	B9	6.8	2 13.8	+55 27	103	− 4
14,433	Boss 533	A2	6.5	2 14.8	+56 47	103	− 3
14,489	i Per	A2	5.2	2 15.3	+55 23	103	− 4
14,535	.....	A2	7.5	2 15.8	+56 47	103	− 3
14,542	Boss 535	B9	7.0	2 15.9	+56 56	103	− 3
14,818	10 Per	B1ea	6.2	2 18.2	+56 10	103	− 3
14,899	.....	Ao	7.4	2 19.2	+56 47	103	− 3
14,956	.....	B1	7.3	2 19.6	+57 14	103	− 3
15,316	.....	A2	7.3	2 22.8	+57 22	104	− 2
(15,963)	.....	Ao	8.0	2 28.9	+57 38	104	− 1
16,778	.....	B9	7.7	2 36.3	+59 24	104	+ 1
20,041	Boss 724	Ao	5.9	3 8.2	+56 45	109	+ 1
21,291	Boss 781	B9	4.4	3 21.0	+59 36	109	+ 4
21,389	Boss 786	Aoea	4.8	3 21.9	+58 32	110	+ 3
23,193	Boss 845	A3	5.6	3 38.1	+36 9	126	−13
24,398	ζ Per	B1	2.9	3 47.8	+31 35	130	−15
34,085	β Ori	B8	0.3	5 9.7	− 8 19	177	−24
34,578	19 Aur	A5	5.2	5 13.4	+33 52	141	− 1
35,600	Boss 1310	B9	5.7	5 20.8	+30 7	144	− 1
36,371	χ Aur	B3	4.9	5 26.2	+32 7	144	+ 1
38,771	κ Ori	Bo	2.2	5 43.0	− 9 42	182	−17
39,970	.....	B9	6.0	5 50.9	+24 14	153	+ 1
41,117	χ^2 Ori	B1ea	4.7	5 58.0	+20 8	157	+ 1
43,384	Boss 1578	B3	6.3	6 10.8	+23 46	156	+ 6
44,743	β CMa	B1	2.0	6 18.3	−17 54	194	−13
46,300	13 Mon	Ao	4.5	6 27.5	+ 7 24	172	+ 1
(50,850)	.....	B8	9.1	6 49.8	−18 10	197	− 6
52,089	ϵ CMa	B1	1.6	6 54.7	−28 50	207	−10
53,138	o^2 CMa	B3	3.1	6 58.8	−23 41	204	− 7
58,350	η CMa	B7	2.4	7 20.1	−29 6	210	− 5
59,612	Boss 1968	A3	4.8	7 25.6	−22 49	205	− 1
62,623	l Pup	A2ep	4.1	7 39.8	−28 43	212	− 1
(75,149)	Boss 2360	B5	5.5	8 43.1	−45 32	233	− 1

TABLE I—*Continued*

H.D.	Name	Spec.	Mag.	R.A. 1900	Dec. 1900	l	b
(80,558)	Boss 2509	B8	5.9	9^h15^m4	−51° 8′	241°	− 1°
87,737	η Leo	A0	3.6	10 1.9	+17 15	188	+52
91,316	ρ Leo	B0	3.8	10 27.5	+ 9 49	204	+54
(91,533)	.....	A2	6.2	10 29.0	−58 9	253	0
(92,207)	Boss 2835	A2	5.6	10 33.6	−58 13	254	0
(93,737)	.....	A2	6.1	10 44.2	−59 24	256	− 1
(94,367)	Boss 2901	B9	5.6	10 48.4	−56 43	255	+ 2
(100,198)	.....	A2	6.4	11 26.6	−60 43	261	0
(100,262)	σ^2 Cen	A2	5.3	11 27.1	−58 58	261	+ 2
(100,826)	.....	A0	6.2	11 31.1	−60 44	262	0
(102,878)	Boss 3106	A2	5.6	11 45.5	−62 5	264	+ 1
(103,516)	.....	A2	6.0	11 50.0	−62 43	264	− 1
(104,035)	Boss 3130	A2	5.7	11 53.7	−63 47	265	− 2
(108,002)	.....	B1	7.3	12 19.4	−64 39	268	− 3
(111,613)	.....	A2	5.9	12 45.4	−59 47	271	+ 2
(125,835)	Boss 3686	A2	5.7	14 16.8	−67 44	279	− 7
152,236	ζ' Sco	B1eq	4.9	16 47.0	−42 12	311	0
154,090	k Sco	B1ea	4.9	16 58.2	−33 59	319	+ 3
160,529	.....	A4ea	6.7	17 35.3	−33 27	323	− 3
161,912	ι^2 Sco	A3	4.9	17 43.1	−40 4	318	− 8
164,353	67 Oph	B7	3.9	17 55.6	+ 2 56	357	+11
165,784	.....	A2	6.6	18 2.6	−21 28	337	− 2
166,937	μ Sgr	B8ea	4.0	18 7.8	−21 5	338	− 3
168,814	.....	A2	7.3	18 16.6	−14 26	345	− 2
169,454	.....	Boe	6.8	18 19.6	−14 2	345	− 2
183,143	.....	B9ea	6.9	19 23.0	+18 5	21	− 1
190,066	.....	B0	6.6	19 58.1	+21 52	27	− 6
190,603	Boss 5150	Boeβ	5.7	20 0.7	+31 56	37	0
190,919	.....	B1	7.3	20 2.2	+35 24	40	+ 1
197,345	α Cyg	A2ea	1.3	20 38.0	+44 55	52	+ 1
198,478	55 Cyg	B2ea	4.9	20 45.5	+45 45	53	+ 1
199,478	Boss 5389	B8ea	5.8	20 52.4	+47 2	55	+ 1
202,850	σ Cyg	A0	4.3	21 13.5	+38 59	52	− 8
206,165	9 Cep	B2	4.9	21 35.2	+61 38	70	+ 7
207,260	ν Cep	A2	4.5	21 42.6	+60 40	70	+ 6
207,673	.....	A0	6.5	21 45.6	+40 40	58	−10
212,455	.....	B3	8.4	22 19.3	+54 44	71	− 2
212,593	4 Lac	B8	4.6	22 20.4	+48 58	68	− 7
(213,470)	.....	A2	(6.7)	22 26.5	+56 43	72	− 1
218,376	1 Cas	B1	4.9	23 2.4	+58 53	78	− 1
223,385	Boss 6111	A2ea	5.6	23 44.0	+61 40	83	0
223,960	.....	A0ea	7.0	23 48.9	+60 18	84	− 1
225,094	.....	B2ea	6.3	23 58.3	+63 5	85	+ 1

toward emission at *Hα* and the intensities of detached lines and of lines of *O* I, *N* I, and *Mg* II in the infra-red.[1]

The list in Table I, while certainly far from complete, may be useful to other investigators. It includes:

[1] *Mt. Wilson Contr.*, No. 486; *Ap. J.*, **79**, 183, 1934.

A. Stars discovered elsewhere
   1. Confirmed from slit spectrograms taken at Mount Wilson.
   2. Not observed at Mount Wilson. The HD numbers are in parentheses. Only those stars are included whose announcements are in such form that no doubt appears to exist concerning the "c" characteristic.

B. Stars discovered at Mount Wilson. Many of these were found during recent work on detached lines.

Messrs. Adams, Joy, and Sanford have kindly made available a large number of spectrograms taken in the course of other investigations. Numerous intercomparisons of spectra by Miss Burwell have been useful.

TABLE II

DISTANCES OF c STARS

(Assumed absolute magnitude −5.0)

APPARENT MAGNITUDE	DISTANCE IN PARSECS	
	log.	Nat.
0	2.00	100
+ 1	2.20	158
2	2.40	251
3	2.60	398
4	2.80	631
5	3.00	1000
6	3.20	1580
7	3.40	2510
8	3.60	3980
9	3.80	6310
+10	4.00	10,000

Although the absolute magnitudes of the stars in Table I are not accurately known, it seems to be the consensus of opinion that −5.0 is a useful approximation. For this value of M, the distances are as indicated in Table II.

Of the 95 stars in Table I, 31 are of types B0–B3; 23, B5–B9; 41, A0–A5. Fifteen are listed as spectroscopic binaries.[2] The number of stars in whose spectra emission is present at $H\alpha$ (usually on the long wave-length edge of an absorption line) is noteworthy.[3] In several instances the intensity of the emission appears to vary. In addition

[2] J. H. Moore, "Third Catalogue of Spectroscopic Binary Stars," *Lick Obs. Bull.*, **11**, 141, 1924.

[3] *Pub. A.S.P.*, **45**, 49, 305, 1933.

PLATE VI

N

E

W

S

N.G.C. 5216 (Bottom) and N.G.C. 5218 (Top)

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to those stars with the designation "e" in Table I, 10 or 12 have exhibited $H\alpha$ emission of very low intensity on grating spectrograms taken recently at Mount Wilson.

The color excesses, E, of 31 stars in Table I have been determined by Joel Stebbins and C. M. Huffer.[4] The average value of E for 10 stars brighter than apparent magnitude 5.0 is +0.13, for 21 fainter stars +0.26, the more distant stars thus appearing to be the more strongly colored.

PAUL W. MERRILL

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September 1934

AN UNUSUAL PAIR OF NEBULAE: NGC 5216 AND 5218

In the course of a survey of extra-galactic nebulae the two objects NGC 5216 and 5218 (α 13^h30^m, $\delta+63°.1$) were photographed with the Yerkes 24-inch reflector on February 20, 1934, the exposure lasting one hour. On later examination of the plate it was seen that these two apparently well-separated galaxies are connected by a faint but definite band of nebulosity. A second plate centered on the same field confirmed the reality of the nebulous link, which is invisible on short exposures and seems not to have been remarked before.

The case is striking, among the small number of pairs known to be physically connected, because of the considerable separation of the two objects in proportion to their size. The distance between their centers is 4'.1—more than twice the major diameter of the larger nebula, NGC 5218, which is of type SBb. Also of interest in relation to the dynamics of such pairs is the short curved arm which apparently continues the connecting band beyond NGC 5216, and can be seen extending toward the southwest in Plate VI.

On the assumption that the larger nebula is a typical spiral, the average distance of the system was computed by Shapley's method.[1] From the apparent photographic magnitude of about 13.4 the dis-

[4] "Space Reddening in the Galaxy from the Colors of 733 B-Stars," *Pub. Washburn Obs. U. Wisconsin*, **15**, 217, 1934.

[1] *Harvard Ann.*, **88**, 96, 1934.

tance comes out as 4 megaparsecs, while an assumed diameter of 2000 parsecs leads to a distance of 5 megaparsecs, indicating that the brightness is normal with respect to the size of the nebula. If this scale is correct, the connecting arm has a length of some 6000 parsecs.

The task of preparing a print of sufficient contrast to allow such faint nebulosity to be reproduced in a halftone was carried out successfully by Mr. E. L. McCarthy.

PHILIP C. KEENAN

YERKES OBSERVATORY
January 1935

TABLES FOR THE COMPUTATION OF THE ORBIT RADII OF ECLIPSING BINARIES

BY G. R. MICZAIKA

S. Gaposchkin[1] calls attention to the assumption made in the computation of orbit radii of eclipsing binaries that the mass of each of the two components is equal to the mass of the sun:

$$\rho_1 = k^3 \rho_2 \; ; \qquad \rho_2 = \frac{0.00672}{P^2 r_2^3} \; .$$

This assumption is not very reasonable in a precise calculation, because eclipsing binaries with periods $P < 1^d.0$ have on the average a smaller mass than those with periods $P > 1^d.0$. The difference η of the total brightness plays also an important part. But if the mass is corrected, then the orbit radius must also have a correction. Therefore Gaposchkin finds the following formulae:

$$\bar{A}' = 6.77 \overset{2}{P^3}, \text{ if } \mu_h + \mu_s \approx 4.2 \odot \; ,$$

$$\bar{A}'' = 5.61 \overset{2}{P^3}, \text{ if } \mu_h + \mu_s \approx 2.4 \odot \; ,$$

$$\bar{A}''' = 4.74 \overset{2}{P^3}, \text{ if } \mu_h + \mu_s \approx 1.5 \odot \; ,$$

$$\bar{r}_{1,2} = \bar{A} r_{1,2} \; .$$

I have given these functions in Table I.

[1] *Veröff. Babelsberg*, **9**, Part V, 1932.

TABLE I

P	A'	A''	A'''	P	A'	A''	A'''
$0^d.20$	2.32	1.92	1.62	$7^d.70$	26.40	21.87	78.48
.26	2.76	2.29	1.93	.90	26.85	22.25	18.79
.32	3.17	2.63	2.22	8.10	27.30	22.62	19.11
.38	3.55	2.95	2.48	.30	27.75	22.99	19.42
.44	3.91	3.24	2.74	.50	28.19	23.36	19.73
.50	4.26	3.53	2.99	.70	28.63	23.71	20.04
.56	4.60	3.81	3.22	.90	29.07	24.08	20.35
.62	4.92	4.08	3.44	9.10	29.50	24.45	20.65
.68	5.23	4.33	3.67	.30	29.93	24.81	20.96
.74	5.54	4.58	3.88	.50	30.36	25.17	21.26
.80	5.84	4.82	4.09	.70	30.79	25.52	21.56
1.00	6.77	5.69	4.74	.90	31.21	25.87	21.85
.15	7.43	6.15	5.19	10.10	31.63	26.22	22.15
.30	8.06	6.68	5.64	.30	32.05	26.56	22.44
.45	8.67	7.19	6.05	.50	32.46	26.90	22.73
.60	9.26	7.67	6.46	.70	32.87	27.24	23.02
.75	9.83	8.14	6.87	.90	33.28	27.58	23.31
.90	10.39	8.60	7.26	11.10	33.68	27.91	23.59
2.05	10.93	9.05	7.64	.30	34.08	28.25	23.87
.20	11.45	9.49	8.01	.50	34.48	28.59	24.15
.35	11.97	9.92	8.38	.70	34.88	28.92	24.43
.50	12.47	10.33	8.73	.90	35.28	29.24	24.71
.65	12.96	10.74	9.07	12.10	35.68	29.56	24.99
.80	13.45	11.14	9.41	.30	36.08	29.89	25.27
.95	13.92	11.53	9.75	.50	36.47	30.22	25.54
3.10	14.39	11.92	10.07	.70	36.85	30.54	25.83
.25	14.85	12.30	10.40	.90	37.24	30.86	26.09
.40	15.31	12.68	10.72	13.10	37.62	31.17	26.35
.55	15.75	13.05	11.03	.40	38.19	31.65	26.74
.70	16.19	13.42	11.33	.70	38.76	32.12	27.13
.85	16.63	13.78	11.63	14.00	39.32	32.59	27.53
4.00	17.06	14.14	11.93	.30	39.88	33.05	27.92
.15	17.48	14.49	12.23	.60	40.44	33.50	28.30
.30	17.90	14.83	12.53	.90	40.99	33.96	28.69
.45	18.31	15.17	12.82	15.20	41.54	34.42	29.07
.60	18.72	15.51	13.10	.50	42.09	34.87	29.46
.75	19.12	15.85	13.39	.80	42.63	35.32	29.84
.90	19.53	16.18	13.67	16.10	43.17	35.77	30.21
5.05	19.93	16.51	13.95	.40	43.70	36.21	30.58
.20	20.32	16.84	14.23	.70	44.23	36.65	30.96
.35	20.71	17.16	14.50	17.00	44.75	37.09	31.33
.50	21.09	17.48	14.77	.30	45.28	37.53	31.70
.65	21.47	17.79	15.02	.60	45.81	37.96	32.07
.80	27.85	18.10	15.26	.90	46.33	38.39	32.43
.95	22.23	18.41	15.51	18.20	46.84	38.82	32.79
6.10	22.60	18.72	15.75	.50	47.35	39.24	33.16
.30	23.09	19.12	16.12	.80	47.86	39.66	33.52
.50	23.58	19.52	16.49	19.10	48.37	40.08	33.88
.70	24.06	19.93	16.84	.40	48.88	40.50	34.23
.90	24.53	20.33	17.18	.70	49.38	40.92	34.59
7.10	25.00	20.72	17.51	20.00	49.88	41.34	34.94
.30	25.47	21.11	17.84	.30	50.38	41.75	35.28
.50	25.94	21.49	18.16	.60	50.87	42.16	35.63

TABLE I—*Continued*

P	*A'*	*A''*	*A'''*	*P*	*A'*	*A''*	*A'''*
20d90	51.36	42.56	35.97	30d80	66.52	55.12	46.58
21.20	51.86	42.97	36.37	31.10	66.95	55.48	46.88
.50	52.35	43.38	36.65	.40	67.38	55.83	47.18
.80	52.84	43.78	36.99	.70	67.81	56.19	47.48
22.10	53.31	44.18	37.32	32.00	68.23	56.54	47.78
.40	53.80	44.58	37.66	.30	68.65	56.90	48.08
.70	54.28	44.97	38.00	.60	69.08	57.25	48.38
23.00	54.76	45.37	38.33	.90	69.51	57.60	48.67
.30	55.23	45.76	38.66	33.20	69.93	57.95	48.97
.60	55.70	46.16	38.99	.50	70.35	58.30	49.27
.90	56.17	46.55	39.33	.80	70.77	58.64	49.56
24.20	56.64	46.94	39.66	34.10	71.19	58.98	49.85
.50	57.10	47.32	39.98	.40	71.61	59.33	50.14
.80	57.57	47.71	40.31	.70	72.02	59.68	50.43
25.10	58.04	48.09	40.64	35.00	72.44	60.03	50.72
.40	58.50	48.47	40.97	.30	72.85	60.37	51.01
.70	58.96	48.85	41.30	.60	73.26	60.72	51.30
26.00	59.41	49.23	41.62	.90	73.67	67.06	51.58
.30	59.87	49.61	41.93	36.20	74.08	67.40	51.87
.60	60.33	49.98	42.25	.50	74.49	61.74	52.16
.90	60.78	50.36	42.56	.80	74.90	62.07	52.44
27.20	61.23	50.73	42.88	37.10	75.31	62.40	52.73
.50	61.68	51.10	43.19	.40	75.71	62.74	53.01
.80	62.13	51.47	43.50	.70	76.11	63.07	53.29
28.10	62.58	51.85	43.81	38.00	76.52	63.41	53.57
.40	63.02	52.22	44.12	.30	76.92	63.74	53.86
.70	63.47	52.59	44.43	.60	77.33	64.07	54.14
29.00	63.91	52.95	44.74	.90	77.73	64.40	54.42
.30	64.35	53.31	45.04	39.20	78.13	64.73	54.70
.60	64.78	53.67	45.35	.50	78.52	65.07	54.98
.90	65.22	54.04	45.66	.80	78.91	65.40	55.26
30.20	65.65	54.40	45.97	40.10	79.31	65.72	55.53
.50	66.09	54.76	46.28				

BERLIN-NEUTEMPELHOF
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REVIEWS

Sir Isaac Newton's Mathematical Principles of Natural Philosophy and His System of the World. Translated into English by ANDREW MOTTE in 1729. The translations revised, and supplied with a historical and explanatory Appendix, by FLORIAN CAJORI. Berkeley: University of California Press, 1934. Pp. xxxv+680+ Frontispiece. Bound, $10.00.

Andrew Motte died in 1730. His translation of the third edition (1726) of the *Principia* appeared in 1729, and was reprinted at least three times (London, 1803 and 1819; New York, 1848). These reprints are accompanied by an English version, first published in 1728, of Newton's *De mundi systemate.* According to Cajori (p. 679), this anonymous version was made by Andrew Motte.

Florian Cajori died in 1930. The volume under review is based on an unfinished manuscript left by Cajori; it was edited by R. T. Crawford. In revising Motte's translation, occasional use has been made of Robert Thorp's partial English version (2d ed., 1802), and of J. Ph. Wolfers' German version (1872). The revision of Motte's translation is characterized by the modernization of obsolete mathematical notations and expressions. Thus, "subtriplicate ratio" is replaced by "cube root of the ratio," "subsesquiplicate ratio" by "2/3th [*sic*] power of the ratio," "reciprocally as" by "inversely as," etc. These changes do not affect the classical beauty of Motte's version; the addition of a short glossary of obsolete mathematical expressions might have been a better solution of the problem of modernization.

The introductory matter includes English translations of Newton's three prefaces (1686, 1713, and 1725–26) and of Roger Cotes's important Preface (1713) to the second edition of the *Principia;* there is also Leon J. Richardson's translation of the ode dedicated to Newton by Edmund Halley, after the Latin text of the first edition.

The Appendix (pp. 627–80) consists of fifty-nine notes prepared by Cajori; of these, only three refer to the *System of the World.* Most notes have titles, and some of them may be considered as short essays, generously supplied with bibliographical references; the following notes could be

quoted as examples: "Absolute Motion and Absolute Time" (pp. 639–44), "Surface of Least Resistance" (pp. 657–61), "Newton's Idea of God" (pp. 668–70), "Newton's Use of Hypotheses" (pp. 671–76), and "Causality" (pp. 676–79). These valuable notes of a philosophical, mathematical, historical, and bibliographical nature take care of the differences between the texts of the third edition (1726) and of the two previous ones (1687 and 1713), as well as of the problems connected with Cotes's Preface of 1713.

The geometrical figures of the *Principia* are taken from the third edition, not from Motte's translation. The historico-bibliographical value of the volume is increased by a facsimile of the title-page of the first edition of the *Principia*, and by a photogravure reproduction, as frontispiece, of a portrait of Newton in the Pepysian collection.

It is only fair to the editor and the publishers to mention the excellence of the proofreading, printing, and binding.

A. Pogo

Il cielo e le sue meraviglie: Atlante di 150 tavole: Riproduzioni di fotografie celesti ottenuti con i più grandi telescopi moderni. By Pio Emanuelli. Milan: Ulrico Hoepli, 1934. Pp. xl+314. Pls. 150. Fig. 1. Cloth, L. 130.–

This atlas of halftone reproductions of selected and classified celestial and terrestrial photographs includes a considerable amount of descriptive and reference material. The reading matter consists of a Preface (pp. vii–xii), a General Introduction (pp. xiii–xxxv), and information concerning the individual photographs. This information—printed on the left-hand pages of the atlas itself, facing the corresponding plates—offers a general description of the object reproduced and gives copious bibliographical references to other photographs and discussions of the same object. At the end of the volume the reader will find lists of technical terms and of abbreviations, a name index, and a subject index. The index of plates (pp. xxxvii–xl), which precedes the atlas proper, shows the major and minor subdivisions of the plate material and, at the same time, of the general introduction. This general introduction dominates the atlas; the 150 plates are, in a way, illustrations to the four chapters of the introduction.

The photographs reproduced on the rectos of the glossy-paper pages 3–301 belong to four groups, corresponding to the four chapters of the introduction: the planetary, the galactic and the extra-galactic systems,

and observatories and telescopes. Practically one-half the plate material furnishes illustrations for chapter i, dealing at length with the planetary system (moon, 14 pls.; sun, 38 pls.; planets, 9 pls.; comets and meteorites, 13 pls.; total, 74 pls.); the last 14 plates of the atlas are illustrations to chapter iv, devoted to observatories and telescopes. This leaves but 62 plates to illustrate chapters ii and iii. It is to be regretted that these chapters, which deal with the Milky Way, the globular clusters, diffuse nebulae, planetary nebulae, the Magellanic Clouds, and spirals, are not as lavishly illustrated as the beginning and the end of the general introduction, which deal with such celestial objects as the moon and meteorites, or with such terrestrial objects as observatory buildings. The introduction contains four additional bibliographies—one at the end of each chapter.

A scientific rather than an aesthetic point of view prevailed in the making of this atlas—in spite of its title.

A. Pogo

The Diffraction of Light, X-rays, and Material Particles. By Charles F. Meyer. Chicago: University of Chicago Press, 1934. Pp. 473. $5.00.

In this work the subject of diffraction is set forth in considerably more detail than is usual in treatises on physical optics, where as a rule a single chapter is given to the subject. The student who recalls the difficulties he encountered in reading the one chapter may perhaps be inclined to "shy away" from this very much more extensive discussion. If, however, he summons enough courage to begin reading, he may have some difficulty in laying the book aside before he has finished at least the first 278 pages. The remaining chapters on X-rays and material particles he will, however, find equally attractive and stimulating.

Dr. Meyer calls his work "an introductory treatment." He begins with an interesting historical outline, which contains many extracts from the works of the pioneers, from Grimaldi to quite recent times, and among other things a brief sketch of the life of Fresnel.

Chapters ii and iii develop in detail and with numerous illustrative examples the geometrical methods used throughout the work. After two more chapters treating typical examples of Fresnel and Fraunhofer diffraction patterns, the author gives in chapter vi a thoroughgoing discussion of the diffraction grating and its errors—in many respects the best treatment of this subject that has come to the reviewer's notice.

Chapter vii, on "Sundry Ramifications of the Diffraction Theory," brings together in 85 pages most of the important problems in diffraction and closes with a clear statement of the limitations of Fresnel's theory, together with a brief discussion of the work of Kirchhoff and Sommerfeld.

The concluding chapters, on "The Diffraction of X-rays and of Material Particles," will be especially welcomed by those who do not specialize in these subjects, for the exposition is very clear and easy to follow.

J. A. ANDERSON

Men, Mirrors, and Stars. By G. EDWARD PENDRAY. New York: Funk & Wagnalls Co., 1935. Pp. x+339. Pls. 31. $3.00.

With the world being thrilled daily with the construction of giant telescopes and with so many amateur astronomers busy building telescopes of their own, this history of the telescope should be well received. The author is the science editor of the *Literary Digest*, and the book is written in popular style for the general reader.

In a very broad sense this book is at the same time a history of telescopes, a history of astronomers, and a history of astronomy, for, as the author says, all three are closely interwoven. The author has carried out the scheme very well. Part I begins with a description of the visible universe and an account of early astronomical instruments and early observations; then it tells the story of the invention of the telescope and traces its gradual development, showing how each improvement in the telescope led to new discoveries and how each discovery inspired new improvements in the telescope. Part II is devoted to a description of the telescope's accessories and their uses, and Part III is an account of famous telescope-makers and famous telescopes now in use and under construction. As a conclusion, the author conjectures regarding telescopes of the future. There is also a well-arranged Appendix listing the world's largest telescopes and giving data of the major observatories of North America and of the Southern Hemisphere. The illustrations throughout are excellent and are aptly chosen.

Men, Mirrors, and Stars, judged as a popular book, is well written and makes excellent reading. The chapter on famous American telescope-makers, for example, is as thrilling as a drama. At the same time, the book must also be judged as an instructive account of astronomy and astronomical instruments. Mr. Pendray has made an honest attempt to

make the book instructive; in this he has sometimes succeeded and sometimes failed. His introduction to stellar spectroscopy and his descriptions of telescope mountings are excellent. On the other hand, there are points about which he is misleading, not to say quite wrong. As an example, the brief account of spherical aberration on page 44, besides being generally confusing, states that for a convex lens the central rays are brought to a shorter focus than the rays near the edge; the reverse is true. Again, on page 78, in describing Bradley's discovery of the aberration of light, the statement is made that the stars nearest the pole (meaning, presumably, the celestial pole) describe nearly perfect circles, those between the pole and the zenith toward the north describe ellipses, while those overhead make a direct north-south line; whereas, in truth, stars at the pole of the ecliptic describe circles, while those in the ecliptic move in a straight line in the plane of the ecliptic and those between the ecliptic and its pole describe ellipses. It is difficult to understand how the author could have become so confused.

There is always a tendency for scientifically trained readers to deplore sensationalism in popular scientific writings. Mr. Pendray will be forgiven for much of this because he does it so well, but one cannot but feel that his fantastic conjectures about the future of astronomy in the last chapter defeat his own end by seeming to dwarf the advances which astronomy has made. Who can continue to marvel at the 200-inch reflector when he is asked to contemplate a 100-foot telescope located in a glassed-over crater of the moon?

Notwithstanding the points of error and exaggeration, *Men, Mirrors, and Stars* is a notable and original effort which will be appreciated by the astronomer and by the general reader.

J. F. HEARD

Theoretical Physics. By GEORG JOOS. Translated from the first German edition by IRA M. FREEMAN. New York: G. E. Stechert & Co., 1934. Pp. xxiii+748. $6.50.

In his Preface to this translation of Joos's *Lehrbuch*, Dr. Freeman speaks of its suitability as a convenient reference work as well as a textbook. This comment defines well the field of usefulness of the volume. Covering a wider range of topics than such well-known introductions to the subject as those of Leigh Page and of Slater and Frank, it will probably offer somewhat more difficult going for the student who seeks to use it as a

text for individual study; but, on the other hand, the encyclopedic manner of treatment renders it especially serviceable as a source of reference on specific problems. The translator has helped not a little in this respect by adding an adequate index and extending the bibliography and footnotes.

The volume opens with a mathematical introduction, followed by the customary material on mechanics, with the addition of a descriptive chapter on relativistic mechanics. The next portion, dealing with electricity and magnetism, is divided into two parts. In the first, which is devoted to the mathematical relationships between macroscopically measurable quantities, the field theory of electromagnetic and optical phenomena is presented. The more fundamental atomistic approach is reserved for the second part, where the electron theory is introduced by a discussion of the conduction of electricity in solutions, gases, and metals.

The theory of heat also is developed separately from two points of view: the phenomenological and the atomistic. Under the latter heading the brief introduction to kinetic theory leads naturally to an excellent summary of classical statistics, supplemented by a chapter on the Bose-Einstein and the Fermi-Dirac statistics.

The last section of the book is given over to as much of atomic theory and quantum and wave mechanics as can be crowded into eighty pages. At the end there has been added a chapter on nuclear physics which is included in the second German edition now making its appearance.

The author is to be congratulated upon condensing so much material into relatively little space without great sacrifice in clarity of presentation. Credit must be given to the translator also for preserving this quality in the English version.

We are tempted to regret that no work of this type includes a satisfactory treatment of the theory of radiative equilibrium, but that will more properly form part of a textbook of theoretical astrophysics.

P. C. K.

Actualités scientifiques et industrielles. Exposés d'astronomie stellaire by HENRI MINEUR: No. 115, *Histoire de l'astronomie stellaire*, pp. 57, price 15 fr.; No. 116, *Eléments de statistique mathématique*, pp. 40, price 12 fr.; No. 141, *Photographie stellaire*, pp. 67, price 18 fr. Paris: Herman & Cie, 1934.

To this large collection of pamphlets covering recent developments in a wide variety of subjects by French-writing scientists, Mr. Mineur has

contributed three fascicules concerning stellar astronomy. The material is condensed into so few pages that the treatment is necessarily sketchy. Some parts seem to have been written very hurriedly; and the reader notices a great number of errors: in No. 115 we are surprised at the statement that reflectors with ratios of aperture of 1/4 or 1/3 cover large angular fields, that α Aquilae, β Urs. Min., and φ Urs. Maj. are among the early-found spectroscopic binaries. The maps showing the distribution of observatories on the various continents are interesting illustrations, but they are marred by such errors as shifting the Victoria Observatory from Vancouver Island to the Canadian province of Alberta, the Kazan Observatory from the Volga to Turkestan, and the Kodaikanal Observatory from India to Ceylon. In No. 141 the statement that a visual telescope cannot be used for photography is exaggerated, in view of the fact that for a decade hundreds of stellar parallaxes have been determined photographically with such instruments. In connection with the transformation of standard into equatorial co-ordinates, the author refers the computer to the tables in the introductions of most of the volumes of the *Astrographic Catalogue*. These unwieldy tables have long been the main stumbling-blocks in the use of this catalogue. One misses any mention of the simple Hamburg table, which covers all cases in a single 6×7-inch page. Nevertheless, the author has presented here a number of useful facts that have not before been compiled in a logical sequence from recent literature.

G. V. B.

The Calculation of the Orbits of Asteroids and Comets. By KENNETH P. WILLIAMS. Bloomington, Ind.: Principia Press, 1934. Pp. vii+214. Bound, $3.25.

This subject has been treated so frequently that it seems difficult to make a substantial addition to its literature. Without making an original contribution to the solution of the problem, the author has succeeded in making a most interesting presentation; the methods are logically developed on a good historical background (too often neglected by modern writers) while at the same time the most recent contributions to the subject are mentioned. In order to make the presentation clearer and more concise the deductions often differ from the form in which they were originally published. Proper references are given to more detailed investigations, and numerical examples of the various computations are also given. The exercises at the end of each chapter will be of great help

in giving the student a better insight into the problem. The subject of definitive orbits or perturbations is not included in the plan of the book, which is devoted mainly to the derivation of first elements. In keeping with the present tendency to use the calculating machine in place of logarithmic computation, the former method receives the proper emphasis. In this connection it is a little unexpected to find (p. 75) a numerical example of Kepler's equation solved by logarithms when the calculating machine would have led much more rapidly to the result, since we have now excellent tables of natural values of trigonometric functions with the argument in decimal fractions of a degree. Also the use of "constants other than those of Gauss" in the computation of an ephemeris by a machine would have deserved more than passing mention. More inclusive works have appeared in various languages on this subject, but few will be found more useful to a beginner than the present volume. It is carefully edited, and with its moderate price it should have a wide distribution.

G. V. B.

Encyclopédie photométrique, quatrième section, Tome 4: *Photométrie des lumières brèves ou variables*. By MME M. MOREAU-HANOT. Paris: Editions de la *Revue d'optique theorique et instrumentale*, 1934. Pp. 126. Fr. 25.

This little volume, belonging to that section of the *Encyclopédie photométrique* which deals with *cas extrêmes*, reviews visual, photographic, and photo-electric investigations of rapidly varying sources of light. The laws of response to radiation are summarized for these methods of measurement, references to numerous original papers being included in the text. Among the subjects discussed are visual thresholds of perception, persistence of vision, intermittency effect in photography, methods of producing flashes of known duration, properties of photo-electric cells, and the electrical transmission of images.

P. C. K.

Rydberg Interpolation Table. Princeton: Departments of Physics and Astronomy of Princeton University, 1934. Obtainable from the secretary, Princeton University Observatory. Pp. 20. $1.00.

The wave numbers of spectral lines represent differences between Rydberg terms of the form $R/(n+\mu)^2$, and tables giving these terms for

intervals of the order of 0.05 in the values of $(n+\mu)$ are in common use. However, the investigation of complicated spectra involving perturbed series requires terms computed for much smaller intervals. To meet this need the present table gives the values of $109737.4/(n+\mu)^2$ for all values of the denominator from 1 to 11 in steps of 0.001. The computations were carried out by Miss Janet MacInnes and D. N. Read. Preceded by a short introduction by A. G. Shenstone, J. C. Boyce, and H. N. Russell, the table is arranged conveniently, with horizontal and vertical differences printed in small black type between the term values.

P. C. K.

Annual Tables of Constants and Numerical Data. Published under the patronage of the INTERNATIONAL RESEARCH COUNCIL and of the INTERNATIONAL UNION OF CHEMISTRY. McGraw-Hill Book Co. Vol. **8** (2 parts, 1927–1928), pp. 2706; Vol. **9** (1929), pp. 1607. Cloth, Vol. **8**, $20; Vol. **9**, $16.

Numerical Data of Spectroscopy. Reprinted from Vols. **8** and **9** of *Annual Tables of Constants and Numerical Data.* Edited by the INTERNATIONAL COMMITTEE. Secretary C. Marie, Paris VI°; 9 rue de Bagneux. Pp. 1397. Cloth, $8.00.

Numerical Data of Spectroscopy. Reprinted from Vol. **10** of *Annual Tables of Constants and Numerical Data.* As above. Pp. 306.

These convenient compilations are uniform with earlier volumes of the same series. The collected data on spectroscopy are especially useful to astrophysicists.

Tafeln zur theoretischen Astronomie. By JULIUS BAUSCHINGER. 2d ed. revised by GUSTAV STRACKE. Leipzig: Wilhelm Engelmann, 1934. Pp. v+192. Bound RM. 25.

Bauschinger's tables have been used quite generally by computers of orbits since their first publication in 1901. They have, however, been out of print for a number of years. The initiative taken by Dr. G. Stracke, a pupil of Bauschinger, in publishing a second edition is therefore a welcome one. During this first third of the century, mechanical computers have

come into competition with logarithmic tables, the use of the decimal division of the degree has gained much favor, and various improvements have been made in the methods. The new edition reflects these trends and thus its usefulness is increased. Tables that can better be found in the yearly ephemerides have been omitted, but a number of useful ones have been added, so that the volume has become about one-third larger than the first edition.

G. Van Biesbroeck